

**Identifying temperature breaks in pome fruit and table grape export
cold chains from South Africa to the United Kingdom and the
Netherlands: A Western Cape case**

by

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(Logistics Management) in the Faculty of Economics and Management Sciences at
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Abstract

There is a growing concern in the South African fruit industry of increasing losses, both financially and of the produce itself, as a result of temperature breaks in the export cold chain. This concern was so significant that an investigative enquiry was prompted by Company X, a prominent fruit exporter, into the origins of temperature breaks within their export cold chains of apples, pears and table grapes from the Western Cape, South Africa to The Netherlands and the United Kingdom.

Two rounds of observations were conducted. Firstly, in South Africa at the farms, pack houses, cold stores and Cape Town Container Terminal. Secondly, in Europe at the Port of Rotterdam and the first European cold store. Further analysis was done through the temperature trials conducted from February to July 2018. This enabled a deductive, mixed methods research approach where the qualitative data aided the understanding of the quantitative data. The data analysed began from the pack houses in South Africa and concluded at the first distribution centre within the country of import.

The analysis of the data collected highlighted and confirmed suspected areas prone to temperature breaks as well as identified new, unsuspected areas. Three chief problem areas of the South Africa leg, across all three fruit kinds, were identified. These include the pack house and cold store, in and around the gate-in point of the container at port and just prior to the vessels Actual Time of Departure (ATD). A further three problem areas were identified in the pome fruit trials only. These included just after Actual Time of Arrival (ATA) of the vessel, during the barge stage and at the point where the container was destuffed. The impacts of the unsuspected heat gained, especially by the pome fruit, in the initial stages of the cold chains were shown to have far reaching and long-lasting, detrimental effects for entire pallets and thus, ultimately the entire containers. A further key insight gained was the importance of fruit respiration rates and its relationship with temperature.

The research provided key insights into identifying weak links within the export cold chains of deciduous fruit. The results of the research demonstrated this with the number of temperature breaks, their frequency and durations recorded within certain stages as well as detrimental effects on the quality of the fruit. Company X can use the findings of the research to adjust current practices to prevent temperature breaks

from occurring in future and diminish the quality of the final product. Furthermore, with the insights of Company X, the efficiency of the entire export cold chain as a whole could be improved. This increase in efficiency could lead to possible financial incentives such as cost savings, environmental savings such as cooling efficiency and reduction in food waste as well as even possibly a higher quality end product with a longer shelf life.

Keywords:

Cold chain, fresh fruit exports, logistics, South Africa, temperature breaks

Opsomming

Daar bestaan toenemende kommer in die Suid-Afrikaanse vrugtebedryf oor die jaarlikse verliese wat die bedryf lei as gevolg van temperatuuronderbrekings in die uitvoerkoueketting. Hierdie verliese is so beduidend dat Onderneming X, 'n gesiene vrugte-uitvoerder, 'n ondersoek geloots het om die oorsake van temperatuuronderbrekings in hul uitvoerkouekettings van appels, pere en tafeldruiwe, wat vanaf die Wes-Kaap, Suid-Afrika na Nederland en die Verenigde Koninkryk verskeep word, te bepaal.

Waarnemings was verdeel oor twee sessies. Die eerste sessie was in Suid-Afrika op die plase, pak huise, koelkamers en in die Kaapstad Hawe se vraghouer terminaal. Tweedens, in Europa, in die hawe van Rotterdam en gedurende die verplasing na die eerste Europese koelkamer. Addisionele inligting is ingesamel deur middel van temperatuur steekproewe gedurende Februarie en Julie 2018. Hierdie inligting het 'n proses van eliminasië en 'n gemengde metodes-navorsingsbenadering moontlik gemaak waar kwalitatiewe data die kwantitatiewe gegewens ondersteun het. Dataversameling het in die Suid-Afrikaanse pakhuis begin en geëindig by die eerste distribusiesentrum in die invoerende land.

Die data-analise het die areas wat geneig is tot temperatuuronderbrekings geïdentifiseer en bevestig, asook nuwe onverwagte areas uitgewys. Die drie belangrikste probleemareas van die Suid-Afrikaanse been, oor al drie vrugtesoorte, is geïdentifiseer. Dit sluit die pakhuis, koelkamer, deur van die vraghouer by die hawe, asook die tydperk net voor die skepe se werklike tyd van vertrek (ATD), in. 'n Verdere drie probleemareas is tydens die kernvrug steekproewe geïdentifiseer. Dit het die tydperk onmiddellik na die werklike tyd van aankoms (ATA) van die vragskip, die skeepsfase en punt van aflaai ingesluit. Die onverwagte hitte wat, deur veral die boomvrugte, gedurende die aanvanklike stadiums van die koueketting ervaar is het vërreikende en langdurige negatiewe gevolge gehad op die palette en, daarom, uiteindelik op die vraghouers ook.

Die navorsing het belangrike insigte gelewer vir die identifisering van swak skakels in die uitvoerkouekettings van sagtevrugte. Die resultate het aangedui dat die aantal temperatuuronderbrekings, hul frekwensie, en tydsduur wat in sekere gevalle aangeteken is, nadelige gevolge vir die kwaliteit van die vrugte ingehou het.

Onderneming X kan die bevindinge van die navorsing gebruik om hul huidige praktyke aan te pas en, daardeur, temperatuuronderbrekings in die toekoms voorkom. Sodoende, kan die onderneming kwaliteit verliese in die toekoms verminder. Hierdie insigte kan vir Onderneming X help om die doeltreffendheid van hul hele uitvoer koue ketting te verbeter. Hierdie toename in doeltreffendheid, kan lei tot finansiële besparings soos kostevermindering. Dit kan ook lei tot omgewingsbesparings deur verkoelingsdoeltreffendheid te verhoog en voedselafval te verminder. Hierdie besparings sal uiteindelik lei tot vrugte van hoër gehalte met langer rakleefte.

Sleutelwoorde:

Koue ketting, uitvoer van vars vrugte, logistiek, Suid-Afrika, temperatuuronderbrekings

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Chapter 1: Introduction

1.1 Introduction and background

South Africa is ranked as the third largest deciduous fruit producer in the southern hemisphere with Chile and Argentina claiming the top two positions (Hortgro, 2017). Deciduous fruits are comprised of pome and stone fruit as well as table grapes. Stone fruits are comprised of apricots, peaches, nectarines, plums and prunes, while pome fruits consist of apples and pears. The distinction is made based on their core, as stone fruits have a 'stone' or 'pit' at their core, which contains the seeds, while pome fruits' seeds are encased by a membrane (Horticulture, [n.d.]).

The South African primary agricultural sectors' economic contribution to the South African Gross Domestic Product (GDP) in 2015 was estimated at R72.2 billion, according to the DAFF Economic Review of South African Agriculture in 2016 (DAFF, 2017c). Fresh fruit exports were valued at approximately R26 billion of that (Fresh Produce Exporters Forum, [n.d.]). Although this can be seen as a relatively smaller sectors contribution to GDP, the agricultural sector has a more far reaching, indirect role to play in the economy. The sector is a significant provider of employment, especially in more rural communities, where unemployment rates are often high with many dependents on a sole income earner. The sector is also a major generator of foreign exchange (forex), due to its high exporting nature. Fresh fruit exports comprise 33% of all of South Africa's agricultural exports, with 2.7 million tons exported to more than 90 countries worldwide (Fresh Produce Exporters Forum, [n.d.]).

To facilitate the exporting process, especially that of fresh produce, there are strict guidelines, protocols and procedures put in place and regulated by various bodies and other invested parties, that must be adhered to throughout the entire supply chain. Thus, a specific kind of supply chain, known as a cold chain, is used to facilitate these measures and ensure a smooth as possible integration between all parties involved theoretically and practically. This is the point where the management of the cold chain is factored in. The Council of Supply Chain Management Professionals defines supply chain management as, "encompassing the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel

partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies. Supply Chain Management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance and information technology” (Council of Supply Chain Management Professionals, 2016). This is the definition that is used throughout this research.

A generic deciduous fruit cold chain is depicted in Figure 1.1. Its simplicity is for simple interpretation purposes, but it should be kept in mind that there are many specific protocols and procedures that take place throughout the cold chain.

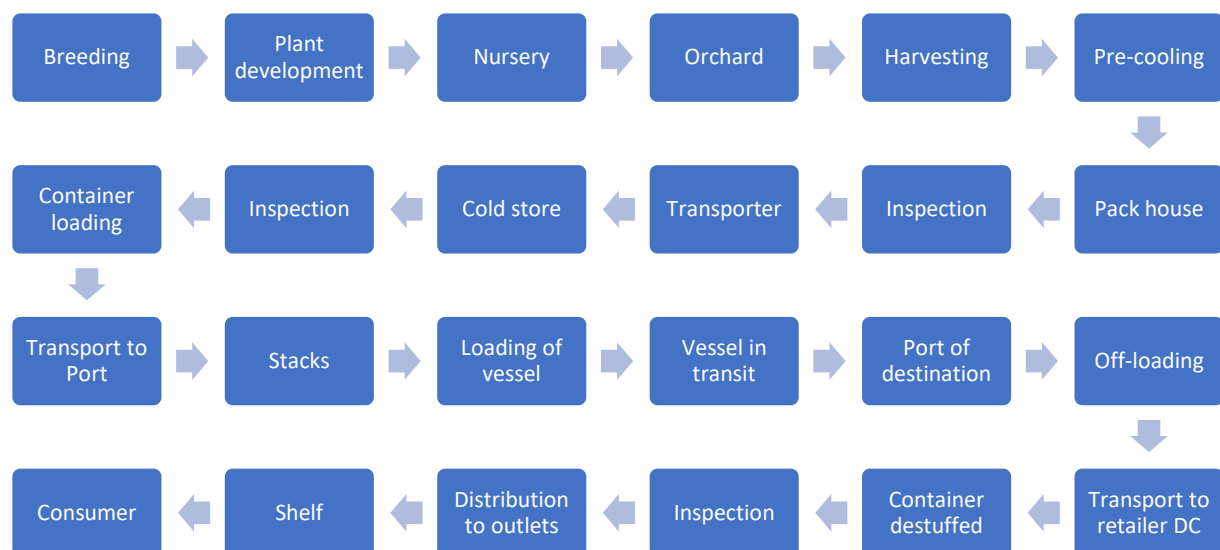


Figure 1.1: Generic deciduous cold chain flow diagram

Source: Jacobs, 2018 ; Roxburgh, 2018 ; Van Dyk & Maspero, 2004

The cold chain begins at the point of harvest on a farm where the freshly picked fruit is put into crates, collected by a tractor and transported to a cooled or refrigerated room, usually at the pack house facility. This serves to remove the field heat from the fruit and is known as pre-cooling. This type of cooling is known as room cooling and

is the most commonly applied method of pre-cooling (PPECB HP02, n.d.). It is important for field heat to be removed as soon as possible after harvest and once the process of lowering the fruits' temperature has begun, it must continue on this downward trend. This is not only to prevent a break in the cold chain, but also to preserve and deliver the highest quality final product to the end consumer. Grapes and apples are brought into the precooling stage in crates, but while grapes are left in the crates before being placed onto the pack house lines, apples are often placed in a water bath to remove the field heat. This is known as hydro cooling (PPECB HP02, n.d.). There is a rule of thumb that table grapes have a maximum time of six hours before they must be under pre-cooling once harvested. As a result, table grapes are often packed at a pack house on site before being transported to a cold store. Pome fruits are often transported from farms to a centralized or regional pack house before being transported to a cold store for Forced Air Cooling (FAC). Both pome fruit and table grapes undergo FAC, but pome fruit can be put into controlled atmospheric conditions where it can be stored for several months. Controlled atmospheric conditions are a storage method in which the concentrations of nitrogen, oxygen and carbon dioxide, in conjunction with temperature and relative humidity, are controlled. This gives pome fruit a much longer shelf life than table grapes. The fruit remains at the cold stores until they are due for export, whereafter they are containerized and moved onto the next link in the cold chain.

The next stage is the containerised journey to the port. At this stage, the fruits will be at their protocol temperature as directed by the PPECB and the importing country's requirements. For apples and pears, it ranges from -1.5°C to -0.5°C depending on its packaging and varietal (PPECB HP22,n.d.), while table grapes need to be transported at -0.5°C , but their pulp temperatures can reach a maximum of 1.5°C or 2.5°C depending on the export code used (PPECB HP22,n.d.). This temperature is required to be maintained for the full duration of the container's voyage on board the vessel. It is important to note that despite the fact that refrigerated containers, known as reefers, and sometimes refrigerated trucks are used during this transport leg, the fruit must already be at protocol temperature. The reefer containers and refrigerated trucks purpose is not to bring the fruits' temperatures down to protocol temperatures, but rather to maintain them at those temperatures. Additional considerations when using reefer containers is that of the cold stores' facilities, which will dictate if a container

should be cooled or not prior to stuffing. Only if the cold store is equipped with airlocks at its loading bays should the containers be pre-cooled. This is to lower the risk of condensation forming inside the container, which results in a phenomenon known as container rain. Container rain can have devastating results on produce, such as sulphuric acid burn on table grapes, due to the excess water from the condensation coming into contact with the sulphur packaging sheets (Jacobs, 2018).

Once at the port, the reefer containers are connected to a power source and stacked in a container yard often referred to as 'the stacks. It is important that the length of time the reefer container spends unplugged during the transition from the truck to the stacks is kept to a minimum to avoid any temperature spikes. Once the vessel is ready to be loaded, the container will again be unplugged, loaded and then reconnected to the vessel's power supply. The container will remain in transit until the vessel arrives at the port of destination, where this process will then be repeated in reverse. The container will ultimately be transported to the relevant retailer's distribution centre where it will be destuffed, the pallets broken down and transported to the relevant retail outlets where the fruits will be made available for sale to end consumers.

Deciduous fruits are quite temperature sensitive (Aung & Chang, 2014) and once they have entered the cold chain and their temperatures begin to lower, their temperatures may not rise again. This not only impacts on the fruits temperature, but it effects the fruits quality, which includes aspects such as its shelf life and taste, which then influences its price. The temperature sensitivity of fruit can be attributed to simple postharvest physiology. Fruits are living things and therefore, respire to produce energy. Pome fruits are fuelled by starch, while table grapes use organic acids and sugars (PPECB HP02, n.d.). Naturally, these energy reserves are depleted over time, which results in a faster senescence process and amongst other things, ultimately results in a deterioration of the fruit quality. Temperature control management can assist in extending the life span of fruit as lower temperatures slow down the respiration rate of the fruit and decrease moisture loss, pathogen viability and other quality weakening aspects. According to the Perishable Product Export Control Board (PPECB), "temperature abuse is the prime reason for loss of product quality" (PPECB HP02, n.d.). Furthermore, temperature control management is not only limited to the

time the fruit is on board a vessel or inside a container, but rather starts from the moment the fruit is harvested and continues until it is consumed by the end consumer.

1.2 Motivation

There is a growing concern in the South African fruit industry of increasing losses, both financial and of the produce itself. Experts in the industry attribute these increasing losses to a decline in fruit quality. As temperature is the most significant factor in the senescence of fruit, could the decline in fruit quality be attributed to breaks in the cold chain? The notion was significant enough to prompt an investigative enquiry by Company X into their export cold chains of deciduous fruit from the Western Cape, South Africa to Europe and the United Kingdom.

1.3 Problem statement

There is a growing concern that the South African fruit export industry is losing a significant amount of money each year as a result of breaks in the cold chain. These temperature breaks within the cold chain could result in possible load rejections at importing customs and large financial losses. This is a great concern as fresh produce is a resource intensive product. With environmental constraints and economic factors, such as the recent drought experienced in the Western Cape as well as South Africa's current unemployment rate, all linked to the production aspect of the fruit, ensuring that avoidable losses are avoided is crucial to the efficiency and effectiveness of the entire supply chain.

A number of studies have been conducted over the years investigating cold chains. Many of these studies focused on certain aspects in a section of the cold chain only and often conclude at the port of import. Examples include those where emphasis was placed on the farm to port of export only, only within the port itself as well as between the port of export and the port of import. There have been little to no studies done looking at a single supply chain in its entirety, from producer to end consumer or the transport leg from the port of export to end consumer. Thus, this study endeavoured to investigate the current gap in the knowledge of identifying the temperature profile along the export cold chain of pome fruit and table grapes from farms in the Western Cape region of South Africa to retailers in the Netherlands and United Kingdom.

Due to restrictions and other practical limitations, the research started as close as possible to these points, thus, from the pack houses of the fruit in South Africa and

concluded at the first DC in the country of import. The research also strived to link any breaks in the cold chain to quality issues experienced when the fruit arrives at the first DC's in the country of import.

1.4 Research objectives

The primary objective of this research was to map and track the temperature profiles of apples, pears and table grapes exported by Company X from South Africa to Europe and the UK for a complete as possible export cold chain.

Due to restrictions and other practical limitations, the research commenced from the pack houses of the fruit and concluded at the first DC in the country of import. The research also strived to link any breaks in the cold chain to quality issues experienced when the fruit arrives at the first DC's in the country of import.

1.5 Research questions

- 1.5.1 Do temperature breaks occur along the export cold chain of pome fruit and table grapes from the Western Cape to Europe and the United Kingdom?
- 1.5.2 Where and with what frequency do the temperature breaks occur?
- 1.5.3 How long do the temperature breaks last for?
- 1.5.4 If temperature breaks were experienced, did containers with more temperature breaks have worse quality reports than those with fewer temperature breaks?
- 1.5.5 What was the effect of the temperature breaks on the physical fruit quality?
- 1.5.6 Are there any current measures in place attempting to inhibit temperature breaks from occurring and do they impact on fruit quality?

1.6 Aim and purpose

The aim of this research is primarily to identify if, where, with what frequency and for how long temperature breaks occur along the export cold chain of apples, pears and table grapes starting from the vineyards and pack houses to the first DC in the country of import. The main purpose of the research is to achieve a complete as possible, cold chain temperature profile of deciduous export fruit originating in the Western Cape of South Africa bound for the European and United Kingdom markets. Through the mapping and tracking of the fruits temperature profiles, weak points where temperature breaks occur can be identified. The information can be used to resolve the underlying issues to ensure the problem no longer occurs and diminishes the final

quality of the fruit, while supporting the supply chain to run more efficiently as a whole. The increased efficiency could lead to some financial incentives such as cost savings and possibly even increasing the overall quality of the fruit.

1.7 Structure

1.7.1 Chapter 2: Research design and methodology

Chapter 2 discusses the flow of the research as well as the methodology followed.

1.7.2 Chapter 3: Literature review

Chapter 3 gives an introduction to the concepts pertinent to the research. It includes a background on the South African fruit industry as well as fruits as a whole, cold chain practices terminology and the importance of temperature within this cold chain. Role players such as the PPECB, DAFF and ports involved are also discussed. Lastly, international best practices and advancements are discussed.

1.7.3 Chapter 4: Observations

Chapter 4 provides a brief discussion as well as visualisation of the observations made during the research.

1.7.4 Chapter 5: Data analysis

Chapter 5 discusses the results of the research temperature trials. Tables, graphs and further analytical discussions are used to illustrate the results further.

1.7.5 Chapter 6: Interpretation of results

Chapter 6 involves the interpretation of the results, graphs and tables discussed in Chapter 5.

1.7.6 Chapter 7: Conclusions and recommendations

The final chapter provides a synopsis of the findings of the research conducted. In addition, recommendations are made and suggestions for possible future research are provided.

2 Research Design and Methodology

2.1 Introduction

Chapter two includes a sequential discussion of the execution of the research. The types and sources of the data are also discussed.

2.2 Design and methodology

The research followed a deductive research approach. A mixed-method research approach was applied through the collection of quantitative and qualitative data. Facilitation was the specific mixed methods approach used (Bryman, Bell, Hirschsohn, dos Santos, du Toit, Masenge, van Aardt & Wagner, 2016:62), as primary and secondary qualitative data gathered was used to aid the quantitative aspects of the research.

Secondary data was first gathered through a review of current available literature on related topics. The sources of the information include books, journal articles as well as the internet. This provided the researcher with a foundation of background knowledge and understanding of the fruit exporting industry in both a South African and international context, industry jargon and terminology used as well as role players along the export cold chain.

Primary qualitative data was gathered through observations of the fruit export cold chains. These observations took place on farms, at pack houses and cold stores as well as at the ports. Additional primary qualitative data was gathered through informal interviews to better understand observations and answer queries linked to observations, between the researcher and staff of the aforementioned facilities and Company X. Primary quantitative data was gathered through the data logged during the use of temperature monitoring devices such as iButtons® and TempTales®. The temperature monitoring devices were inserted within and amongst the fruit at the start of the export cold chain and followed throughout the cold chain and its transit phases until the devices were removed at the respective distribution centres in Europe. The temperature monitoring devices generated both pulp and ambient temperature data and built an accurate depiction of the fruits temperature profile throughout its export cold chain.

Temperatures were measured and monitored using temperature monitoring devices inserted in two ways, namely, an invasive or non-invasive manner. The invasive method recorded the pulp temperature of the fruit via the insertion of the device into a specific fruit. However, this approach did result in the loss of that specific fruit. The non-invasive method was done by placing the temperature monitoring devices inside the carton, amongst the fruit, so that the device can experience the same environment as the fruit. The devices had long, red ribbons attached to them for easy identification within the cartons. In addition to the red ribbons, the TempTale® devices are bulky making them easy to spot within the cartons. This aided in the ease and speed of the retrieval of the devices. The iButtons® are much smaller than the TempTale® devices, but the ambient ones were attached to a credit card sized holder with a long red ribbon. This also added to the ease and speed of device retrievals. iButtons® used to measure the pulp temperature of fruit were clearly marked, not only on the cartons and pallets themselves, but on the individual fruits as well. This helped to ensure that the iButtons® were clearly visible and minimised losses during the retrieval process. Company X elected that both options be used to gather the data required for this study.

Through the assistance of a statistical expert and Professor from the Centre for Statistical Consultation (CSC) at Stellenbosch University, a power analysis was done to determine a suitable sample size. A three-way ANOVA was used, which had a factorial design with three factors at 3, 3 and 2 levels, thus, 18 treatment combinations or cells. This resulted in a total of 72 subjects required to provide four subjects per cell. The within-cell standard deviation is 1.000. This design achieves a 95% power when an F-test is used to test the factors at a 5% significance level and the actual standard deviation among the appropriate means is 0.471. The 0.471 is also known as the effect size. The power is the probability of rejecting a false null hypothesis, n is the average sample size of a cell and N is the total sample size of all the groups combined. Therefore, the minimum sample size was determined to be 216 temperature probes ($A= 72$, $B= 72$, $C= 72$, thus $A+B+C = 216$). The numeric results are depicted in Figure 2.1.

Numeric Results									
Term	Power	n	Total N	df1	df2	Std Dev of Means (Sm)	Effect Size	Alpha	Beta
A	0.94574	4.00	72	2	54	0.471	0.471	0.05000	0.05426
B	0.94574	4.00	72	2	54	0.471	0.471	0.05000	0.05426
C	1.00000	4.00	72	1	54	1.000	1.000	0.05000	0.00000
AB	0.88311	4.00	72	4	54	0.471	0.471	0.05000	0.11689
AC	0.94574	4.00	72	2	54	0.471	0.471	0.05000	0.05426
BC	0.94574	4.00	72	2	54	0.471	0.471	0.05000	0.05426
ABC	0.88311	4.00	72	4	54	0.471	0.471	0.05000	0.11689
Standard Deviation of Subjects: 1.000									

Figure 2.1 Numerical results from three-way ANOVA

Source: Neter, Kutner, Nachtsheim and Wasserman, 1996. & Winer, 1991

The 216 temperature monitoring devices were divided between twelve containers per trial. These twelve containers each contained six probed pallets with devices situated in the top, middle and bottom cartons of the pallet. Thus, three temperature monitoring devices per pallet x six pallets per container = 18 devices per container x 12 containers = 216 temperature monitoring devices and the sufficient sample size. In addition, the twelve containers also needed to be spread across a minimum of four vessels.

For the pome fruit trials, the temperature monitoring devices used for the pulp temperature were iButtons® while TempTale® devices were used to measure the ambient temperature. As there was a limitation of the number of devices available for the trial, there was not a sufficient number to have both a pulp and ambient temperature monitoring device in the top, middle and bottom cartons. It was decided that pulp temperature readings were a more accurate representation of the fruits' temperature profile and would ultimately provide more meaningful end results. Thus, only one TempTale® device was inserted per pallet and placed in the top carton for all the pallets in the trial. This gave the study an element of uniformity and enabled the results to be compared. The top carton was selected, as the most temperature variance is found in the top cartons due to the basic principles of physics where heat rises while cool air sinks. In addition, all the refrigerated containers (reefers), used in the trials have a bottom air delivery system. This means the airflow within a container begins with cold air, also known as delivery air, being pumped into the container at the bottom, travelling up through the T-bar floor and then the pallets before reaching the top of the container and being drawn into the returned air point. This circulation pattern also results in warmer air being found towards the top of the container (Bosman, 2018).

For the table grape trials, the temperature monitoring devices used were only TempTales®. The individual grape berries were too small to have an iButton® inserted. However, a stainless-steel TempTale® 4 probe was used to skewer loose berries to achieve a pulp temperature reading in the top, middle and bottom cartons of certain pallets. Again, due to the limited number of devices available and the single use nature of the TempTales®, a pulp and ambient temperature monitoring device per carton was not possible.

The methodology used in this study has been established and proven through previous research within the deciduous fruit industry as discussed in section 3.12. These methods have also been widely accepted throughout the industry and are often mirrored by internal control measures put in place by exporters, cold stores and shipping lines for their own quality assurance and quality control purposes.

2.3 Concepts, constructs and variables

The main construct and variables of this research are temperature centric. The construct being temperature with a unit of measure in degrees Celsius, °C. The variables consist of the specific ambient and pulp temperatures logged by the temperature monitoring devices as well as possible temperature spikes and the daily regional temperatures of the farms or pack houses when the devices were inserted. Pack house temperatures as well as the temperatures of the trucks and containers are also variables being considered. There are also additional constructs that are linked to that of the temperature profile of the fruit that are equally important, but secondary objectives of the research.

These sub constructs include quality. Quality encompasses all aspects relating to the quality of the fruit. These include, but are not limited to, taste, sugar and starch levels, shelf life, colouring, firmness, blemishes and bruising. Quality control reports, also known as QC's, are looked at in chapter five.

Another sub construct is that of price with the variables being predominantly cost centric. This refers to the costs incurred to get the product ready for export. It is looked at from two perspectives, firstly from the farmers and secondly, from Company X. Thus, these costs include things such as production costs, packaging costs and transportation costs as well as administrative costs. Although apples can be kept under controlled atmospheric conditions, which incurs chemical costs, only fresh

produce bound for immediate export are looked at in this research. This sub construct is considered as it brings a homogenous, quantifiable aspect to the research. It also attaches a monetary value to the reasoning and justification for premiums charged for the end product. In addition, if the end product is spoiled and needs to be discarded, it can assist in determining the full extent of the loss incurred in monetary and resource terms.

The final sub construct is time. It has an overlapping influence between the price and quality of the fruit. There are firstly, strict regulations regarding the maximum amount of time table grapes have post-harvest, before they must be under cooling. It should also be kept in mind that fruit is a perishable product and therefore, the longer it takes to get the product from farm to retailer for the end consumer to purchase, the less shelf life it has in store, the lower its end quality will be and the less the retailer will be able to charge for it and even possibly the higher the risk of no sale being made and the retailer incurring a loss.

2.4 Research risk and ethical implications

This research had low to minimal research risk as the identities of all parties involved were not disclosed and thus referred to throughout the research as 'Company X', 'Farm Y', 'Shipping line Z' and 'Retailer A'.

All human participation in this study does not pertain to the sharing of personal information and therefore limits the degree of ethical implications and/or repercussions. Permission was, however, requested and granted by Company X, both locally and internationally, as well as the farms, shipping lines and retailers involved, to gain access to the required quantitative and qualitative data. Non-disclosure agreements were also signed by the required parties as a further measure to protect all parties' interests.

Non-disclosures were also be signed by the researcher, as a prerequisite of Stellenbosch University. Lastly, all interviews and conversations were kept confidential and not shared amongst other parties involved. This served as an additional measure to protect all parties' interests. This information was also stored on a password protected personal computer.

Semi-structured interviews were conducted and were used to substantiate the understanding of data gathered. This included the explanation of processes involved within the supply chain, such as fruit growth and varietal choice. These interviews were conducted in person or telephonically, at an agreed upon time, between the participant and the researcher deemed most convenient.

3 Literature Review

3.1 Introduction

Secondary research was conducted through the reviewing of existing literature on subjects relating to aspects of the research. Digital databases with e-journal archives were most commonly used to gain access to information on related research. The literature review provided the researcher with a broad foundation of insight to better understand the complexity of the export cold chain as well as the specific parties involved throughout the export process. Additional knowledge was gained on a variety of contributing aspects, such as basic cold chain operations and the importance and various contributing factors that all play a role in the effective and efficient control of temperature within a cold chain. Furthermore, additional insights were gained into the effects and roles of packaging and horticulture to a lesser degree.

3.2 Fruits

There are four major plant types in the plant kingdom, namely; Mosses and Liverworts, Ferns, Gymnosperms and Angiosperms. Angiosperm is the botanical name for flowering plants (Kirsten, 2017), which are responsible for ultimately producing what is commonly known as fruit. Botanically speaking, a fruit is defined as, “a mature, or ripened ovary of a flower along with its contents and any adhering accessory structures...” (Simpson & Ogorzaly, 1995:84). There are two types of fruit, namely, true and false fruits. True fruits, such as grapes, are formed from a single superior ovary only, while false fruits (for example apples), also called accessory fruits, are formed from the ovary as well as extra or accessory parts of the flower as depicted in Figure 3.1 (Simpson & Ogorzaly, 1995:88).

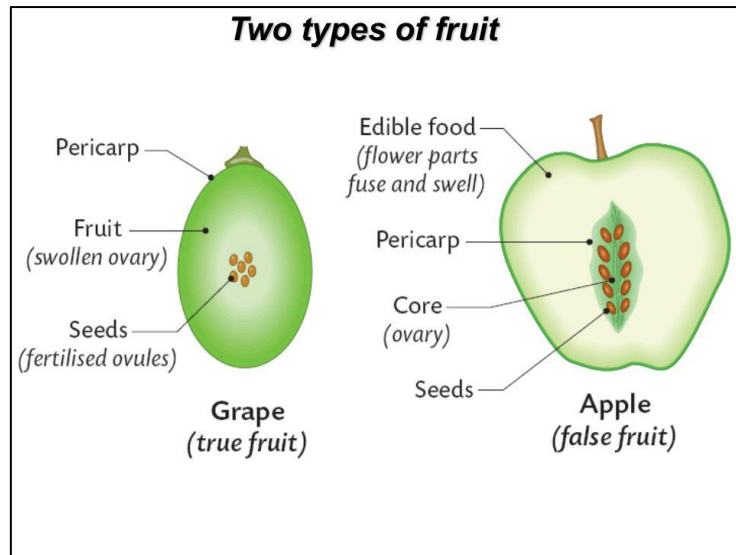


Figure 3.1 True and false fruit types

Source: Sexual Reproduction in Flowering Plants, n.d.

Apples and pears as well as plums, strawberries and raspberries are part of the wider *Rosaceae* or rose family (Simpson & Ogorzaly, 1995:81). The *Rosaceae* family is further subdivided into four sub-families to account for the structural differences within the various fruit kinds. More specifically, pome fruits (apples, pears and quinces), fall under the *Maloideae* subfamily, as it is the floral hypanthium that becomes fleshy in order to form the fruit as highlighted with the red box in Figure 3.2 and further illustrated in Figure 3.3.

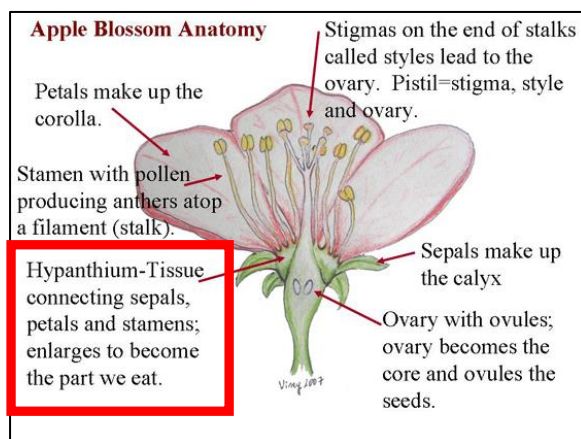


Figure 3.2 Apple Blossom Anatomy

Source: Viney, 2007

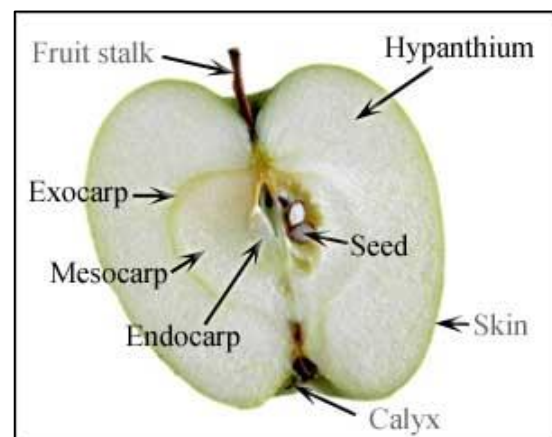


Figure 3.3 Apple cross sectional

Source: Plant Lab, n.d.

Grapes also fall under the angiosperm plant type, but are part of the *Vitaceae* family (Simpson & Ogorzaly, 1995:81). Thus, vining, flowering plants. Grapevines

specifically, are known as vitis (Encyclopaedia Britannica, 2019) and so lends its name to the science, study and production of its fruit and its fruits' by-products, namely wine, known as viticulture and viniculture. According to Nikolai Vavilov, a renowned Russian botanist, agronomist and geneticist; apples, pears and grapes genus originated in Indochina before being domesticated and grown into the varieties of the crops known today (Simpson & Ogorzaly, 1995:81).

There are four main fruit categories grown in South Africa, more specifically, deciduous, citrus, sub-tropical and exotic fruits. These fruit categories as well as the season in which they grow, are shown in Figure 3.4.

South Africa: Abridged seasonal fresh produce calendar



















































































































































DECIDUOUS FRUIT	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Apricots												
Peaches												
Nectarines												
Plums												
Table Grapes												
Pears												
Apples												
Kiwi												
Cherries												
CITRUS FRUIT	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Easy Peelers & Mandarins												
Lemons												
Oranges												
Grapefruit												
SUB-TROPICAL FRUIT	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Avocados												
Litchi's												
Mangoes												
Pineapples												
Passion Fruit												
EXOTIC FRUIT	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Raspberries												
Blueberries												
Melons												
Strawberries												
Figs												
Pomegranates												

Figure 3.4 South African fresh fruit seasons

Source: DAFF, 2016a

3.3 Deciduous fruit

The deciduous fruit industry consists of stone and pome fruits as well as table grapes. Stone fruit examples include apricots, peaches, nectarines, plums and prunes, while pome fruit examples include apples, pears and quinces. The distinction between the two is made based on their cores. Stone fruits have a ‘stone’ or ‘pit’ at their core, which contains the seeds, while pome fruits’ seeds are surrounded by a membrane (Department of Primary Industries Australia, n.d.). Botanically, the fruits are also in different subfamilies, as pome fruits form part of the Maloideae subfamily, while stone fruits are a part of the Amygdaloideae subfamily (Petruzzello, 2014; Simpson & Ogorzaly, 1995:93).

3.3.1 Pome fruits

Pome fruits, such as apples and pears, experience an almost identical export cold supply chain as illustrated in Figure 3.5. The green highlighted block indicates controlled atmosphere, long-term storage, which is not always part of the cold chain. Pome fruit is moved throughout the pack house by means of water. The water serves a dual purpose of firstly, washing the fruit and secondly, transporting it throughout the pack house with minimal injuries such as bruising.

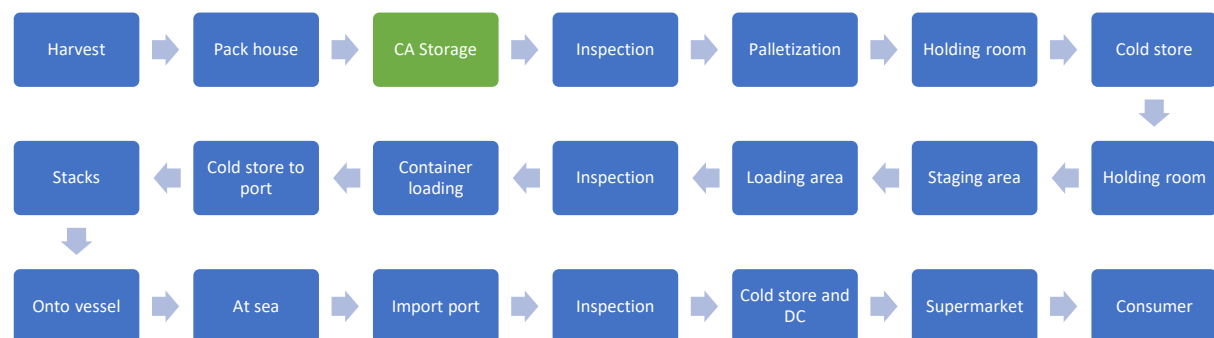


Figure 3.5 Generic pome fruit cold chain

Source: Authors own interpretation

3.3.1.1 Diseases and pests

Deciduous fruit is susceptible to two main types of diseases, namely, fungal or bacterial diseases. The most common fungal diseases are powdery mildew and apple scab also known as black spot (SA Orchards Diseases, 2014). Apple scab is one of

the most common, but highly damaging fungal diseases that affect apples and pears. It releases spores that then attack both the leaves of the tree and its fruit. The disease does not usually kill the tree, but greatly hinders its fruit yield as well as fruit quality. The best way to prohibit this disease is through a preventative programme such as a fungicide spray prior to rain (SA Orchards Diseases, 2014). Powdery Mildew can affect pome as well as stone fruit, but it is especially damaging to nectarines, peaches and apricots. This fungal disease flourishes in high temperatures with moist weather conditions. It effects the leaves, stems, flowers and fruit of the tree (HORTGRO: Monitoring diseases, 2016). The fungus starts as a small, black dot, which in turn develops into larger, white to grey, powder-like spots or areas. Powdery mildew is rarely fatal, but it does stress the tree and can result in impaired photosynthesis, which can diminish the size and flavour of forming fruit. A preventative measure is to spray a fungicide according to a spraying programme every two weeks (SA Orchards Diseases, 2014).

Deciduous fruit is also susceptible to bacterial diseases, but apricots, peaches and plums are more susceptible than any other fruit types. Bacterial diseases can only be treated with antibiotics, but this is illegal in most parts of the world (SA Orchards Diseases, 2014). Thus, the immune system of the tree must be built up to resist the bacterial diseases on its own. Examples of bacterial diseases are bacterial kanker, crown gall and bacterial shot hole (HORTGRO: Monitoring diseases, 2016).

Insects and other pests are also a great concern for deciduous fruit farmers. South African apples are susceptible to 34 insect pests from 13 families (Prinsloo, Uys, ESSA, 2015:350), while South African pears are susceptible to 26 insect pests from 13 families (Prinsloo *et al.*, 2015:366). Many of the insects that attack apples also attack pears and vice versa, but not all are economically harmful. There are approximately 20 overlapping species of insect that affect South African deciduous farmers with varying severities (SA Orchards Insects, 2014). There are six insects, however, that are of great importance as they can decimate an entire crop within a week. These insects are the bollworm, codling moth, oriental fruit moth, false codling moth, Mediterranean fruit fly and snout beetle.

The bollworm and all three moth varieties are essentially moth larvae. The moths will initially lay their eggs on the leaves and/or fruit of the tree whereafter the hatched

larvae burrow into the fruit and ultimately destroy it. The penetration spot may become damaged and even sunken in. The codling moth and oriental fruit moth can decimate an entire crop within a week (SA Orchards Insects, 2014 & Prinsloo *et al.*, 2015:351). Mediterranean fruit flies lay their eggs under the skin of the fruit, whereafter the hatched larvae eat and tunnel through the fruit flesh. This ultimately destroys the fruit flesh and makes the fruit unmarketable (SA Orchards Insects, 2014). Snout beetles are nocturnal and ascend the fruit trees at night to eat the flesh of the fruits. These insects can destroy an entire crop overnight (SA Orchards Insects, 2014).

There are various methods of controlling unwanted insects. These include chemical, biological, cultural, mechanical, Sterile Insect Technique (STI) and Integrated Pest Management (IPM) (Fresh Produce Exporters' Forum. 2013:58). Chemical methods use synthetic or organic pesticides with broad or specific spectrum coverage, such as an insecticide cover spray, which is diluted in water and sprayed over an entire crop area. The effects of the sprays can range from simple baiting to mating disruption (SA Orchards Insects, 2014). Baiting is when an attractant laced with insecticide is sprayed into the orchard. As the insect feeds, it will ingest the insecticide and die shortly thereafter. Mating disruptions occur when female pheromones are placed in and along the orchards, which attracts the males to the area. The males incessantly proceed to search in vain for the females, whereafter they die a frustrated death. Biological methods involve using a naturally occurring enemy of the pest to keep the unwanted pest under control or eradicate it entirely. Cultural control methods involve pre-planning on behalf of the farmer to temporarily adjust cultivation practices to prevent the spreading of pests. This includes, for example, the cleaning and sterilization of tools from one infected area to an uninfected one. Mechanical methods are the control of pests through physical means such as traps or removal of affected leaves by hand. SIT can be thought of as birth control for insects. SIT pertains to the breeding and release of sterile male insects, which mate with wild females and result in infertile eggs. IPM is a pest control plan that considers the entire ecosystem of the orchard/vineyard including the plants, animals and surrounding habitat as well as the human and financial aspects of the orchard/vineyard (Fresh Produce Exporters' Forum. 2013:55).

Deciduous fruit is susceptible to two main pests while in orchard. These are soil nematodes and woolly apple aphids. Plant parasitic nematodes are worm-like

creatures that live in the soil as well as plant tissue while feeding off of the plants' roots. Not all nematodes are bad, on the contrary, many found in soil are actually very beneficial as they feed on bacteria and fungi and are essential to maintaining soil health. The most dangerous nematodes to plants are the root knot nematode and the cyst nematode. Plant parasitic nematodes can be treated through the fumigation of the soil during soil preparation, but this also kills all good nematodes, good bacteria, earth worms and other desired inhabitants of the soil (What is a nematode, 2015 ; SA Orchards How to control Insects and Pests, 2013).

Woolly apple aphids can live both above and below the ground. They feed off of the tree juices from either the roots if they are underground or off of the tree bark if they are above ground. They can be controlled and treated in two ways. Firstly, a systemic insecticide can be used as it will be taken up through the roots of the plant and passed across the entire plant, including its leaves and stems. As the aphid ingests the tree juices, it will also ingest the insecticide and die shortly after the consumption thereof (SA Orchards Insects, 2014). Alternatively, there is a more natural solution and an example of a biological pest control method. The introduction of a predatory wasp named *Aphelinus Mali* into the orchard could control and reduce the aphid population without the use of any pesticides. If the fruits remain free from pests and diseases, the next hurdle is to avoid storage defects and injuries in order to be of the highest quality and make it into the export market (SA Orchards How to control Insects and Pests, 2013 & Fresh Produce Exporters' Forum. 2013:97).

3.3.1.2 Storage Defects and injuries

Pome fruits' storage life can be doubled or even tripled through modern means of storage such as controlled atmosphere. These methods can, however, sometimes result in defects and possible injuries to the fruits. There are five main defects that occur in pome fruits, namely; water core, bitter pit, cork spot, superficial scald and core flush (Fresh Produce Exporters' Forum. 2013:90).

Water core is a physiological disorder that some apple and Asian pear varieties are susceptible to. It can occur both during storage as well as with mature fruit still on the tree (Fresh Produce Exporters' Forum. 2013:91). The condition manifests in translucent parts of the fruit's flesh associated with diminishing membrane integrity, which, when severe, can lead to internal breakdown of the fruit.

Bitter pit is a disorder where roughly spherical, small, dry and brown patches of dead, collapsed cells occur in the flesh of the fruit. These patches or pits, are usually just below the surface of the fruit's skin and have a bitter taste, which gave rise to the name of the condition (Fresh Produce Exporters' Forum, 2013:91). The condition begins in the orchard, but worsens during storage.

Cork spot is a condition found mainly in pears. It results in the maturing fruit having an uneven and bumpy appearance. This later turns into large grey to brown corky areas that appear if the skin of the fruit is removed (Fresh Produce Exporters' Forum, 2013:91).

Superficial scald is where irregular brown patches appear on the skin of pome fruits after they have been in prolonged storage (Fresh Produce Exporters' Forum, 2013:92). These symptoms often worsen once the fruit has been removed from long-term storage and in severe cases, the scalded area will become sunken.

Core flush is a condition where the core of the fruit discolours into a pinkish, brownish or yellowish hue and is most common in Granny Smith apples. The condition usually occurs at a late stage during storage and tends to be more severe at lower temperatures (Fresh Produce Exporters' Forum. 2013:92).

3.3.1.3 Apples

There are approximately between 7 500-10 000 known apple cultivars listed in the European Apple Inventory (Watkins, 1985 & Prinsloo *et al.*, 2015:350) that are grown globally for their discernible, characteristic differences such as flavour and firmness as well as for their different uses such as eating, cooking and alcohol production. The largest apple producer worldwide is China contributing approximately 49% to global production. The United States of America are the second largest with approximately 5% of global production. Turkey, Poland and Italy round out the top five with 3.89%, 3.83% and 2.75% respectively (WAPA, n.d.; FAO, n.d.). South Africa is ranked as the 16th largest apple producer contributing approximately 1% to global apple production (WAPA, n.d.; FAO, n.d.).

3.3.1.3.1 Apple climatic requirements

Apples can be grown in a variety of climates from temperate to semi-arid, subtropical and even tropical environments (Musacchi & Serra, 2018). Some wild apple varieties

are found up to 2000m above sea level, where the seasonal temperature fluctuations can range from -30°C to +30°C (Fresh Produce Exporters' Forum. 2013:73). For the same reason, Faust (2000:137), identified four general climates that influence apple as well as apple tree growth and quality. Firstly, a climate characterised by cool days and cool nights would produce good quality fruit, but tree growth is moderate resulting in a smaller tree with a lower yield. Examples of this kind of area include places such as England and northern France. Secondly, a climate characterised by warm days and cool nights is ideal to produce high yielding apple trees with high quality apples. These arid climate regions include New Zealand and Australia as well as central Italy. The third climate is similar to that of the second, as the days are also warm, but the evening temperatures tend to be more moderate and not as cool. This type of climate produces moderate yielding apple trees with good quality apples. California, central Chile and the surrounding areas of the Mediterranean Sea are typical examples of such a climate. Lastly, the fourth climate consists of an area with both warm days and nights such as those found in Japan and southern France. This is the lowest yielding climate out of the four. Climatic regions two and three are most preferential, but require irrigation to produce fruit at their maximum potentials (Musacchi & Serra, 2018).

3.3.1.3.2 Apple growing regions in South Africa

In South Africa, the apple season spans from January to August as shown in Figure 3.4. The majority of apple orchards are planted in the Western Cape (Fresh Produce Exporters' Forum. 2013:73), but orchards are also found in the Eastern Cape, Mpumalanga and Free State provinces as depicted by the black dots in Figure 3.6. Apple orchards accounted for approximately 24 156 hectares planted in the 2017 Hortgro Tree Census (HORTGRO. 2017). That equates to slightly over 30% of deciduous fruits' total production area planted. In the 2017 season, the Golden Delicious variety had the most hectares planted with 5 701 hectares or 23.6% of the total hectares planted attributed to it. The second largest variety is the Royal Gala with 4 142 hectares (17.1% of total hectares planted) planted followed by Granny Smith with 3 718 hectares (15.5% of total hectares planted).



Figure 3.6 Apple production regions in South Africa

Source: DAFF, 2017e

3.3.1.4 Pears

There are approximately 3000 known pear varieties worldwide (Elzebroek and Wind, 2008:25) of which two main species are grown for consumption, namely the Asian and the European pear (Fresh Produce Exporters' Forum, 2013:73). The largest pear producer globally is China as they produce approximately 69% of the world's pears. The second largest global pear producer is the United States of America with a contribution of approximately 3.2%. The next largest global contributors are Italy with 2.96%, Argentina with 2.87% and Turkey with 1.84%. South Africa is the 7th largest pear producer globally with an approximate 1.37% contribution (WAPA, n.d. ; FAO, n.d.).

3.3.1.4.1 Pear climatic requirements

Pears are grown in both the northern and southern hemispheres as they can tolerate and even flourish in a wide range of climatic regions. Specific climatic requirements can, however, vary depending on a variety of reasons, including, but not limited to, the variety grown and the location of the growing area. Pear trees can tolerate temperatures as low as -27°C in the winter months when the tree is dormant and as high as 45°C in the summer months when the tree is experiencing a growing period (*Pear: Pyrus communis*, n.d.; *Agrifarming India*, 2015.). Different pear varieties need a different number of hours where the tree experiences a certain level of cold during the winter. Pear trees need to experience a certain number of hours below 7°C (APAL, 2014) during the winter months in order to end its dormancy and begin the flowering

process to ultimately form fruit. This is known as a chilling requirement and typically varies from 500-1500 hours (APAL, 2014).

3.3.1.4.2 Pear growing regions in South Africa

The Western Cape Province accounts for more than half of all pear production areas in South Africa with the Ceres region responsible for 35%. Other main producing regions include Wolseley/Tulbagh (14%) and Groenland (13%), all in the Western Cape with Langkloof East (14%) in the Eastern Cape (DAFF, 2017a) as depicted in Figure 3.7. According to the 2016 HORTGRO Tree Census, of the 12 280 hectares planted, the main pear cultivar currently grown is Packham's Triumph with 33% at 4 064 hectares. It was followed by Forelle with 26% at 3 219 hectares, Williams Bon Chretien with 20% at 2 515 hectares and lastly, Abate Fetel with 7% at 800 hectares (DAFF, 2017a).



Figure 3.7 Pear production regions in South Africa

Source: DAFF, 2017e

3.3.2 Table grapes

Grapes, both wild and cultivated varieties, currently consist of approximately 10 000 different cultivars (Fresh Produce Exporters' Forum. 2016:74) with new, additional cultivars being created and added through selective breeding programmes. Grapes can be grown for three primary reasons. Firstly, as table grapes for immediate consumption, secondly, to be pressed for the purpose of making wine and lastly, those destined to be dried and become raisins.

China is the largest fresh table grape producer globally with a production contribution of slightly over 49% for the 2017/2018 season. India (13.2%), Turkey (9.3%), the European Union (6.4%) and Brazil (4.3%) round out the top five largest producers with

South Africa ranking tenth with a contribution of approximately 1.3% to global production (USDA, 2017). The largest producer of export table grapes in the world for 2016 was Chile, with approximately 708 001 tons or 17.5% of the total quantity of table grapes exported. The subsequent countries include the United States of America with 11.5%, Italy with 9.3%, The Netherlands with 8.8%, China with 8.3% and South Africa ranked seventh worldwide with 5.5% (South African Table Grape Industry, 2017).

3.3.2.1 Table grape climatic requirements

Climatic requirements vary across the board according to, amongst other things, the location of the growing area and its rainfall, the specific table grape varietal as well as its sensitivity or hardiness against weather conditions. As a result, the macro and micro climate environments play a large role in the success or failure of a vine. The macro environment refers to the larger region and its general climate. There are many factors that need to be considered, such as average summer and winter temperatures, as table grapes require roughly 150-170 frost-free days with a temperature exceeding 10°C to facilitate growth, flowering and then set fruit (Grunert, [n.d.]). To facilitate this, the season must be long enough to allow for both the fruit and vegetative part of the vine to mature, while providing sufficient sunlight hours that, through photosynthesis, provide an adequate supply of carbohydrates. The carbohydrates assist in the maturation of the table grapes and the vines as well as its productive potential to produce healthier vines and sweeter fruits (DAFF, 2012). In addition, there should ideally be very little rain during the ripening stages as this will prevent some diseases to which table grapes can be prone. During the winter, the season needs to be long enough that the vines can enter a period of dormancy, but with no frost as the young buds are sensitive to freezing. This would severely damage and even destroy the flower clusters (DAFF, 2012). Therefore, to produce generally higher quality table grapes, the macro environment should be hot and dry where there are warm days with cool nights and low humidity (DAFF, 2012).

The micro climate is what makes one area better suited for table grape production than another. One of these factors is the soil type. Although table grapes can be grown in a variety of soil types, they do best in a soil with a pH of 5.5-6. (DAFF, 2012). The most important aspect of the soil, however, is that of the water supply and drainage. This influences the roots of the vines, which, according to DAFF, should have “a minimum of 75cm to 1m of permeable soil with no impeding layers for optimum vine

growth” (2012). Healthy roots facilitate healthy and vigorous vines, which increases the chances that the vines will produce good quality, high tonnage yields. Planting in the valleys of sloping hills leading to water sources, such as rivers or lakes, offer many benefits. Firstly, the slopes act as a natural drainage system for the table grape vine roots, which assists in proper development and growth. Secondly, there is the advantage of the microclimate being subtly warmer than its surrounding areas. This is due to warmer air settling in pockets along the valleys and slopes, which, even though hardly noticeable to people, can give the vines a climactic boost. Lastly, as table grape vines are prone to fungus and moulds, but require abundant water, good air circulation is crucially important to prevent unwanted growth of these pests (Grunert, [n.d.]). In more general terms, table grapes across the board traditionally grow best in areas with a mild Mediterranean climate where the weather consists of warm days, cool nights and low humidity (Fresh Produce Exporters’ Forum, 2016: 95; DAFF, 2012). This makes South Africa a prime table grape producing country.

3.3.2.2 Table grape growing regions in South Africa

South Africa has five major table grape producing regions as shown in Figure 3.8. These are, in terms of hectares planted in the 2017 season, namely, the Hex River Valley with 6 543 hectares (33%), the Orange River Valley with 5 705 hectares (29%), the Berg River Valley with 4 525 (23%), the Northern provinces with 1 735 hectares (9%) and the Olifants River Valley with 1 335 hectares (6%). The top cultivars grown in the 2016 season were Crimson Seedless (20%), Prime Seedless (8%), Thompson Seedless (7%) and Flame Seedless (6%) (DAFF, 2017b).

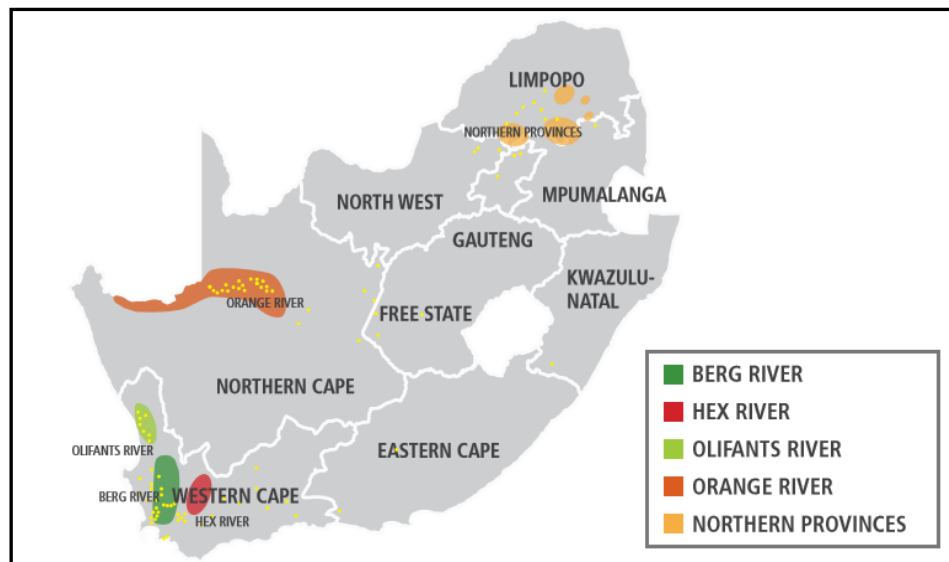


Figure 3.8: Map of table grape growing areas

Source: South African Table Grape Industry, 2017:8

3.3.2.3 Basic SC flow

Table grapes have a relatively straight forward supply chain flow as Figure 3.9 depicts. There is great attention paid to temperature throughout the table grape cold chain, but especially during the field heat removal phase. Once the temperature has begun on its downward trend, it is imperative that it must not rise, but rather remain on its downward trajectory.

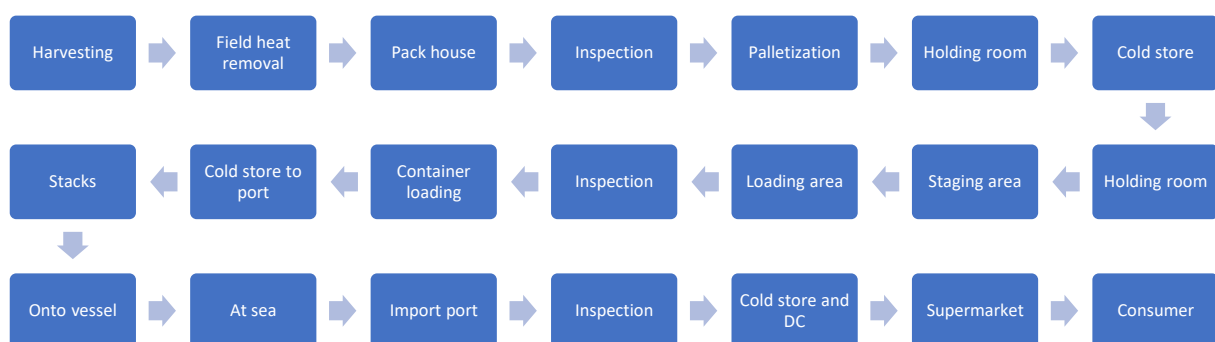


Figure 3.9 Generic table grape cold chain

Source: Adapted from Fresh Produce Exporters' Forum, 2016:107

3.3.2.4 *Injuries, illnesses, diseases*

Table grapes are susceptible to many pathological disorders including fungal, bacterial and viral. Pre-harvest pathological disorders that grapes are susceptible to include; powdery mildew, botrytis rot, phomopsis cane and leaf spot, downy mildew, leafroll virus and bacterial blight (Fresh Produce Exporters' Forum, 2016:66). Powdery mildew, botrytis rot, phomopsis cane and leaf spot and downy mildew are all fungal diseases that result in some form of fungus or mildew growth on either the trunk, shoots, leaves, branches, berries or a combination thereof. As with most fungi, warm temperatures with high humidity or light rain produce the perfect environment for fungal growth and infestations. Leafroll virus, as the name suggests, is a viral disease carried by the vine mealybug (Fresh Produce Exporters' Forum, 2016:67). Leafroll virus reduces the vines production through inhibiting photosynthesis as well as reducing the sugar levels and pigment in the berries, which delays harvesting (Fresh Produce Exporters' Forum, 2016:67). Bacterial blight is a highly contagious pathogen that is listed as a quarantine organism. The bacterium is found in the vascular tissues of the vine and ultimately reduces the health of the vine, which negatively impacts its growing ability.

Table grapes are also susceptible to postharvest pathological disorders which include; penicillium, rhizopus, aspergillus, alternaria and soft tissue breakdown (STB). Penicillium, aspergillus and alternaria are all fungal diseases resulting in visible mould ranging from blue-green in colour to grey and black. Rhizopus is also a fungus, but has no visible symptoms on the berries. It is only once an infected berry is squeezed slightly that it will explode and show its infected inside that is a cobweb-like water mass (Fresh Produce Exporters' Forum, 2016:68). STB is both a pre- and post-harvest disorder. It is caused by a complex combination of pathogens from fungi, yeasts and bacterium that result in the total rotting of the fruit tissue of the berries. This complete rot causes fluids to drip from the berries (Fresh Produce Exporters' Forum, 2016:68). In addition, table grapes are also vulnerable to insects and other pests.

Table grapes are susceptible to 35 insect pests from 14 different families (Prinsloo *et al.*, 2015:420), many of which overlap with those experienced by pome fruit, such as nematodes and false codling moth, as explained in section 2.2.1.1. The most important of which include the six kinds of weevils, the false codling moth, thrips and the mealybug. Weevils, specifically the grey, speckled and banded fruit weevils are

particularly high on the pest control list as they can directly cause grape bud, berry or bunch loss. Thrips, or as they are also known, Western flower thrips, are tiny insects only measuring around 1.2mm in length (Fresh Produce Exporters' Forum, 2016:65). These insects damage the ova before the flowers of the vines have had time to bloom, which inhibits the entire fruit production process. In addition to the damage caused by the Thrips, other pathogens such as Botrytis and Alternaria may set in via the feeding sites of the Thrips (Fresh Produce Exporters' Forum, 2016:65). The grapevine mealybug is a little insect that, to the eye, appears to be covered in a white, powdery, mealy-like wax, hence its name sake. It feeds off of the sap from the vine and in repeated infestations, can weaken the vine so severely, it can result in death (Prinsloo *et al.*, 2015:428). In addition, the mealybug is a primary vector of the Leafroll virus, which can be debilitating for the vine as well as economically (Prinsloo *et al.*, 2015:427; Fresh Produce Exporters' Forum, 2016:65). Methods of pest control in the table grape industry are the same as those used in the pome fruit industry, as previously described in section 2.2.1.1. They include methods such as chemical, cultural, STI and IPM.

With a holistic and knowledgeable approach to fruit production, from fruit formation and climatic requirements for growth to diseases, pests and the treatment thereof, the South African fruit industry is positioned with a solid foundation as a reputable authority on deciduous fruit production.

3.4 The South African fruit industry

South Africa went up in the ranks of the largest deciduous fruit producers in the Southern Hemisphere in 2017, as it surpassed Brazil (HORTGRO, 2016) to come in third, with Chile and Argentina claiming the top two positions (HORTGRO, 2017). The deciduous fruit sub-sector is the largest within the South African fruit industry. In addition, the South African deciduous fruit industry is an export-orientated industry as it prioritizes exports, with approximately 44% of all deciduous fruit produced bound for international markets (Hortgro, 2017).

The structure of the South African fruit industry is made up of five subdivisions that fall under one main body, namely Fruit South Africa, as shown in Figure 3.10. These subdivisions are the Fresh Produce Exporters' Forum (FPEF), HORTGRO, The Citrus Growers Association of Southern Africa (CGA), The South African Table Grape Industry (SATI) and The South African Subtropical Growers Association (Subtrop).

These subdivisions are representatives for all major role players, such as producers, within the South African fruit industry.



Figure 3.10 South African fruit industry structure

Source: Adapted from Fresh Produce Exporters' Forum, 2013:11

The gross value of agricultural horticulture production for the 2016/2017 season was R74 239.6 million according to the Department of Agriculture, Forestry and Fisheries Agricultural Statistics Abstract (2018:76). Of that, deciduous fruit had the largest contribution with R 19 449 328 000, while viticulture had the third largest contribution with R 5 078 477 000 (DAFF, 2018:76). Although their production values may seem relatively small when compared to that of animal production, as the first and third largest contributors to agricultural and horticulture production, their export value, and thus importance, is substantially higher.

According to DAFF and more specifically, the Minister of Agriculture, Forestry and Fisheries Mr Senzeni Zokwana, agricultural exports for 2017 totalled approximately R45.5 billion (DAFF, 2017e) with perishable exports accounting for over 50% of those agricultural exports. This results in the perishable export industry having a monetary value of approximately R 22.75 billion for 2017. Not only are the deciduous fruit and viticulture industries major contributors towards exports and ultimately agriculture's contribution to the South African GDP, but the industries themselves also provide other important benefits to South Africa through means such as employment generators.

3.4.1 Pome:

There are approximately 2 231 deciduous fruit farmers in South Africa with pome farmers accounting for 45% of the total areas planted (Hortgro, 2017). Deciduous fruit farmers generate a total turnover of approximately R12.35 billion per annum and the industry creates 1.34 permanent jobs per hectare (Hortgro, 2017). Thus, for the 2017 season, the industry generated 107 371 equivalent permanent jobs. It is important to note that those 107 371 equivalent permanent positions have 429 485 dependants (Hortgro, 2017). The pome fruit industry accounts for 36 421 hectares allocated between apples (24 156 hectares) and pears (12 265 hectares) respectively (Hortgro, 2017). This equates to approximately 40 421 permanent jobs, with apples and pears contributing 27 297 and 13 124 jobs respectively (Hortgro, 2017). Thus, the pome fruit farmers provide almost 38% of permanent employment in the fresh fruit industry (Hortgro, 2017).

Pome fruit production contributed R8.2 billion in turnover to the agricultural sector in 2015 (Hortgro, 2015), R9.51 billion in 2016 (Hortgro, 2016) and R8.37 billion in 2017 (Hortgro, 2017). Over 90% of the pome fruit industry's income is generated through the fresh sales of its produce (Hortgro, 2016 & 2017). In 2015, the 702 pome fruit producers accounted for approximately 45% of agricultural land use of deciduous fruit production, but generated 78% of the industry's income (Hortgro, 2015). The pome fruit harvesting season runs from January through August, as previously depicted in Figure 3.4, but through technological developments such as controlled atmosphere storage chambers and synthetic quality enhancing products such as SmartFresh, the fruits can be made available all year round. Depending on the method of storage of the fruit, pome fruit can remain in a consumable condition for between twenty days to twelve months (Fresh Produce Exporters' Forum, 2013:54).

The largest export market destinations for apples in 2016 and 2017 were Asia and the Far East with 29% and 31% respectively. The largest export market destination for pears during the same years was Europe with 43% and 37% respectively. The increase seen in the apple exports was partially due to a decline in the production volumes within the European Union (EU), which resulted in raised import volumes from South Africa into the EU during the 2015/2016 season (USDA, 2016). Hereafter, there was an overall increase in apple production volumes in South Africa during the 2016/2017 season, which continued to propel rising export volumes (USDA, 2016).

Production volumes for pears in South Africa during the 2015/2016 season was forecasted to rise slightly, but due to a higher local demand for pears from the domestic processing industry, exports volumes declined (USDA, 2015). This was further exacerbated in the 2016/2017 season as China attained record levels of pear export volumes to Asian markets (USDA, 2016).

3.4.2 Table Grapes

Table grapes are among one of the most globally traded fruit types according to DAFF (2012). South Africa is among the top ten table grape producing as well as exporting countries in the world in terms of both quantity and value (Fresh Produce Exporters' Forum, 2016:87). For the 2015/2016 season, the industry generated R7.1 billion (DAFF, 2017b).

There are approximately 627 table grape farmers in South Africa (SATI, 2015 ; Fresh Produce Exporters' Forum, 2016:99) with 36 422 181 vines accounting for 19 674 hectares planted in 2017 (SATI, 2017). This results in the table grape industry accounting for approximately 25% of the total area planted for deciduous fruit production (79 748 hectares). The industry also generated 8 339 permanent jobs across the five growing regions as well as 43 254 seasonal jobs during the 2016/2017 season (SATI, 2017). The Hex, Berg and Olifants' River Valleys are all located in the Western Cape province and account for approximately 62% of the total table grape production (SATI, 2017; Fresh Produce Exporters' Forum, 2016:97). The remainder is predominantly produced in the Northern Cape Province, along the Orange River, as well as in the other Northern provinces as depicted in Figure 3.8. The five growing regions, with their distinctive climatic differences, allow South Africa to produce a variety of table grapes from October through May for the international market. It is important to note that production volumes decreased slightly in the 2015/2016 season due to a drought. The effects of the drought were further exacerbated during the 2016/2017 season and especially during the 2017/2018 harvest, with factors such as severe water shortages facing the Western Cape region and other extreme weather conditions experienced throughout the country.

average maximum temperatures of approximately 31.4°C and minimum temperatures of approximately 2.3°C with an annual rainfall of 108mm (Fresh Produce Exporters' Forum, 2016:98). The top three cultivars grown and exported during the 2016/2017 season were Prime, Thompson Seedless and Sugraone (SATI, 2017).

The third region to be harvested is the Olifants River Valley, which stretches from Lutzville to Citrusdal in the Western Cape. This area is the smallest table grape growing area and harvest usually takes place from approximately week 50 through to week 12. The Mediterranean, semi-arid climate experiences average minimum and maximum temperatures of approximately 13.5°C to 24.2°C with annual rainfall levels of 280mm (Fresh Produce Exporters' Forum, 2016:99). The top three cultivars grown and exported during the 2016/2017 season in the Olifants River Valley were Crimson Seedless, Red Globe and Flame Seedless (SATI, 2017).

Fourth, the Berg River Valley region is harvested from approximately week 50 through to week 15. This region includes the areas of Paarl, Riebeeck-Kasteel, Piketberg, Saron and Porterville. The Berg River Valley also experiences a Mediterranean, semi-arid climate like the Olifants River Valley, but its average minimum and maximum temperatures experienced range between approximately 5°C to 30°C. The annual rainfall also varies within the region as the north experiences approximately 370mm, while in the south it can rise up to 655mm (Fresh Produce Exporters' Forum, 2016:99). The top three cultivars grown and exported during the 2016/2017 season in the region were Crimson Seedless, Red Globe and Sugranineteen (SATI, 2017).

Lastly, the Hex River Valley region is the biggest table grape producing region in South Africa. The region includes the areas of Worcester, De Doorns, Brandwag, De Wet, Nuy and Nonna. The harvesting period of the region typically commences in week 51 and concludes in week 20. The Mediterranean climate experiences average minimum and maximum temperatures of approximately 23.4°C to 16.4°C with an annual average rainfall of approximately 312mm (Fresh Produce Exporters' Forum, 2016:97). The top three cultivars grown and exported during the 2016/2017 season within the region were Crimson Seedless, Autumn Royal and Red Globe (SATI, 2017).

In order to facilitate the trade of South Africa's fresh fruits that provide various contributions to the country from employment opportunities, substantial GDP

contributions and forex generators (foreign exchange earnings) by way of exports, logistics is required.

3.5 Supply chain basics

Supply chains, logistics and supply chain management are terms often used interchangeably, but they are not the same thing. Supply chains can be thought of as the infrastructure or elements while the activities required to make the infrastructure function or transform the elements, is known as logistics. As a product flows from link to link within the supply chain, and a sequence of transformations takes place, value is added. A supply chain consists of various nodes and links that enable the physical forward and reverse flow of goods. A node is a fixed spatial point within the supply chain where goods are kept or stored for either further processing or consolidation purposes (Coyle et al., 2013:67). An example of a node is a pack house. Links are the transportation networks that connect all nodes in a supply chain in various combinations of the five modes of transport (Coyle et al., 2013:67). Figure 2.12 illustrates a typical fruit supply chain's nodes.

The type of supply chain and the goods within that chain are the main deciding factors that dictate in great detail which kinds of nodes and links would be best suited for the specific supply chain. These can include the kinds of equipment that are used to handle the goods such as forklifts, pallets and racking to specialized or even purpose-built facilities, such as warehouses and cold stores. In a perishable food supply chain, such as fruit exports, there are specialized and unique aspects within the supply chain.

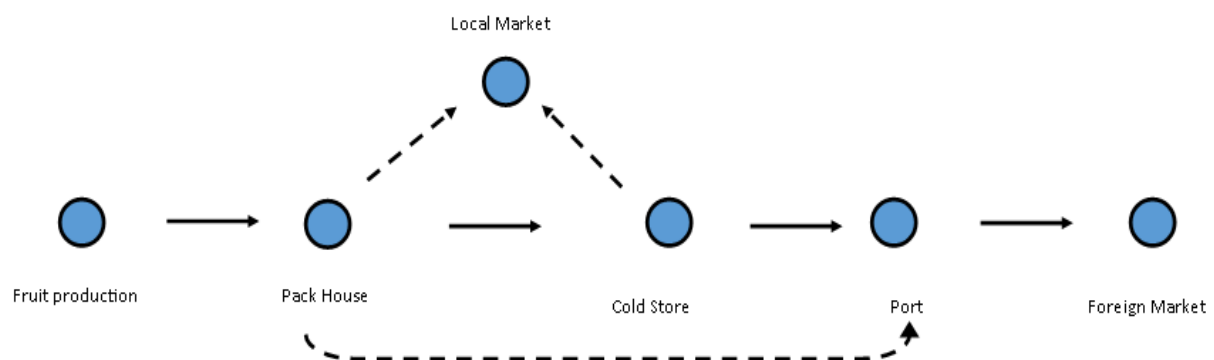


Figure 3.12 Typical nodes of a fresh fruit supply chain

Source: Adapted from Ortmann, 2005

Logistics is found within a single organisations' supply chain as it facilitates the inbound and outbound functions within that supply chain. Supply chain management,

however, is the multi-dimensional integration of many supply chains. Supply Chain Management (SCM), is not a new concept, but the role it plays within business has evolved over time (Coyle, Langley, Novak & Gibson, 2013:17). Initially, SCM was seen as a purely physical distribution concept, concentrated on the outbound logistics division of a business, but over time it has evolved into an all-encompassing and integrative concept. It links all logistics activities and the respective parties involved from inbound to outbound to bring about competitive advantage in a global marketplace. This is achieved through the efficient and effective, forward and reverse flow of three critical elements, namely; information, finances and products or services (Coyle et al., 2013:17).

The Council of Supply Chain Management Professionals defines supply chain management as, “encompasses the planning and management of all activities involved in sourcing and procurement, conversion, and all logistics management activities. Importantly, it also includes coordination and collaboration with channel partners, which can be suppliers, intermediaries, third-party service providers, and customers. In essence, supply chain management integrates supply and demand management within and across companies. Supply Chain Management is an integrating function with primary responsibility for linking major business functions and business processes within and across companies into a cohesive and high-performing business model. It includes all of the logistics management activities noted above, as well as manufacturing operations, and it drives coordination of processes and activities with and across marketing, sales, product design, finance and information technology” (Council of Supply Chain Management Professionals. 2016).

As fruit exporting is a complex supply chain involving numerous parties and requiring specialized equipment and knowledge to function efficiently and effectively, a particular type of supply chain is required. This is known as a cold chain.

3.6 Cold chains

A cold chain, for the purpose of this research, is defined as per the PPECB as, “the seamless and uninterrupted movement of fresh, chilled or frozen products, from the production area to the market, through various storage and transport mediums, without any change in the optimum storage temperature and relative humidity” (PPECB Cold Chain Management, n.d.).

As the definition implies, different products have different protocol temperatures at which they need to be kept to ensure optimal quality upon delivery. To facilitate this, logisticians and transporters alike must ensure the cold chain remains unbroken so that the goods remain at their specified protocol temperatures in order to be delivered to their final destination at their optimum quality. In conjunction to this, a further challenge for transporters is the segmentation found within cold chains as the goods move between locations during processing and within transport modes. An effective cold chain starts at the farms where the produce is harvested and ends once that produce is in the consumer's refrigerator.

3.6.1 Fruit within the cold chain

Fruit is classified as a temperature sensitive commodity (Aung & Chang, 2014). As a result, it is imperative to ensure that the temperatures experienced by the fruit throughout the cold chain are carefully monitored and adhere to regulated stipulations to ensure the fruit is at its optimal quality for the end consumer. Fruits differ in many respects, but one of the most important aspects is its ripening category. There are two ripening categories into which fruit can be classified, namely, climacteric and non-climacteric fruits. The distinction is made based on the rate of respiration of the fruits and ethylene synthesis (PPECB HP02, n.d.; Fresh Produce Exporters' Forum, 2016:53).

3.6.1.1 *Rate of respiration and ethylene*

A fruit is still a living organism even once it has been detached from the plant post-harvest. Thus, it still requires energy for the organism to survive. The energy required is generated through the process known as respiration (Silva, 2010). The respiration rate in fruits is a chemical process through which the fruit converts carbohydrates, usually in the form of either starches or sugars, and oxygen into energy, mostly in the form of heat, as well as water and carbon dioxide (Silva, 2010 ; Goedhals-Gerber, Haasbroek, Freiboth & Van Dyk, 2015). As respiration continues and more carbohydrates are used for energy creation, compounds affecting the fruit's turgor, flavour, sweetness and nutritional value are diminished (Silva, 2010), which has a detrimental effect on the fruit's overall quality. Different fruits have different rates of respiration, but temperature has a substantial effect on the rate of respiration. Temperature has an accelerating effect on the rate of respiration in fruits, which

diminishes the fruit's shelf life as well as quality. According to Silva (2010), "for every 10°C rise in temperature, the respiration rate will double or even triple."

Ethylene is naturally produced by plants during a biological phenomenon known as allelopathy. It is a colourless gas, which is flammable at room temperature, but functions similarly to a hormone as it triggers specific events such as ripening, seed germination and flower initiation among others (Silva, 2010 ; Fresh Produce Exporters' Forum, 2016:53). During ripening, ethylene induces changes such as colour and texture changes as well as tissue degradation (Silva, 2010). Ethylene can also be produced through other means including internal combustion engines, which are found in the vast majority of vehicles. As the effects of ethylene can have desirable and undesirable results, precautions should be taken to minimize unwanted exposure as even small concentrations of ethylene, from natural or artificial sources, can have a detrimental effect on fruit quality.

3.6.1.2 Climacteric and non-climacteric fruit

Climacteric fruits continue to ripen once harvested and exhibit a distinctive peak in their rate of respiration during their ripening phase. They also experience two ethylene production peaks. Firstly, during the flowering phase of development, whereafter it decreases and remains constant during the growth phase. The second peak is experienced at the onset of ripening, where production increases and continues at peak levels until the fruit is ripe (Fresh Produce Exporters' Forum, 2016:53). The rapid increase in the production of ethylene during ripening is mirrored by the fruit's rate of respiration. The respiration rate of climacteric fruits slows during development, but rapidly increases during the ripening process (Fresh Produce Exporters' Forum, 2016:53). This enables the fruit to be harvested once it is mature, but unripe (PPECB HP02, n.d.) as well as handled and transported with minimal damage. This early harvesting property also prolongs the fruit's shelf life. Examples of climacteric fruits include pome fruit, namely apples and pears as well as tomatoes, avocados, bananas, persimmons and kiwis among others.

Non-climacteric fruits do not continue to ripen once harvested and do not experience any significant increases in ethylene production or in their rate of respiration during the ripening process. Thus, non-climacteric fruits must only be harvested when mature and at the ripe stage of development (PPECB HP02, n.d.). As a result, non-climacteric

fruits have a shorter shelf life than climacteric fruits, as they simply begin to decay after being harvested. Examples of non-climacteric fruits include grapes, citrus, pineapples, blueberries, raspberries, strawberries and pomegranates among others.

The primary goal of a cold chain is to maintain the optimal temperature conditions, in line with all specialized and specific requirements and regulations, for the temperature sensitive commodities being transported. It is important to take into account the three most important sources of heat, namely, environmental heat, such as the field heat, respiratory heat generated by the product itself and lastly, generated heat from the operation of the cooling system itself such as during the defrost cycle. Understanding the pivotal role of temperature within a cold chain is imperative to its success.

3.7 Temperature

Temperature is defined by the Oxford dictionary (2017) as, “the degree or intensity of heat present in a substance or object, especially as expressed according to a comparative scale and shown by a thermometer or perceived by touch”. As a cold chain refers to a supply chain in which the temperature is controlled, effective and efficient temperature monitoring and management is crucial to ensure an unbroken chain. This not only includes monitoring the temperature of the fruit itself throughout the cold chain, but also the temperature management of the facilities and their processes in addition to the technology and regulatory protocols of the information systems (Aung & Chang, 2013:199). Good temperature control can slow fruit’s senescence by minimising the occurrence of temperature breaks. This will in turn impact the speed at which textural, colour and other changes occur within the fruit (PPECB HP02, n.d.), ultimately prolonging its shelf life and marketability.

Scientifically speaking, a temperature break would immediately occur when the temperature of the fruit fell slightly above or below the specified temperature. In reality, it is not always practical nor realistic for industry to maintain the cold chain at its precise optimal temperature. Thus, a compromise was reached within the fruit industry that took into consideration both the scientific criteria and acceptable industry bounds. A cold chain temperature break is therefore defined as, “every instance in which the temperature readings rise higher than 2°C or drop lower than -1.5°C (or -1°C in the case of pears) for longer than 90 minutes” (Fresh Produce Exporters’ Forum, 2016:105; Freiboth, Goedals-Gerber, Van Dyk & Dodd, 2013 ; Goedhals-Gerber,

Haasbroek, Freiboth & Van Dyk, 2015). In addition, an important characteristic of temperature breaks is its additive nature, as numerous smaller breaks can have the same adverse effect on the quality of the fruit as one large break (Freiboth *et al*, 2013).

Temperature is the most important aspect to manage when it comes to the perishability of fruit, but the type of fruit and its ripening ability as well as its respiration rate, ethylene production and sensitivity thereof cannot be overlooked. In addition, there are other temperature related factors influencing fruit quality that should be kept in mind.

3.7.1 Moisture, humidity and relative humidity

To understand the concept of relative humidity and its significance within the cold chain, the importance of moisture must first be understood.

3.7.1.1 Transpiration

Transpiration is the term used in industry for moisture loss and is a physiological process whereby the pressure of water vapour both inside and outside of the fruit is equalised (Fresh Produce Exporters' Forum, 2016:122). As with temperature breaks, moisture loss is cumulative in nature and not only manifests in physical quality issues such as saleable weight and appearance, but is also the starting point for many physiological degradation processes. Transpiration is greatly influenced by temperature and humidity. Humidity, simply put, is the amount of water vapour present in the atmosphere. The transpiration process occurs through the movement of water molecules through the skin of the fruit into the surrounding atmosphere through evaporation. The rate of transpiration will increase with higher temperatures as the water molecules within the fruit get more excited as temperatures rise, which increases the capacity of the molecules to escape through the fruit's skin into the atmosphere resulting in a more humid atmosphere, but dehydrated fruit (Fresh Produce Exporters' Forum, 2016:123). Once the atmosphere is saturated, condensation will take place and this point is known as the dew point temperature (Fresh Produce Exporters' Forum, 2016:124). The fruit can be warmed up in two ways; firstly, through sensible heating and secondly, through latent heating. When an object is heated and its temperature begins to rise, the increase in heat is known as sensible heat. Sensible heat is heat that causes a change in the temperature of an object. The condensation of water vapour is known as latent heating, as the water vapour is changing state from

a gas to a liquid, which releases vast amounts of heat and as a result, will heat the fruit.

The dew point temperature is also the temperature at which the relative humidity of the air is at 100%. The dew point temperature determines the possible combinations of temperature and relative humidity that can be possible within a storage environment. It is important to note that at a constant dew point, the relationship between temperature and relative humidity is inversely proportional. Thus, as temperature increases the relative humidity within the same environment decreases and vice versa. This concept is depicted in Figure 3.13.

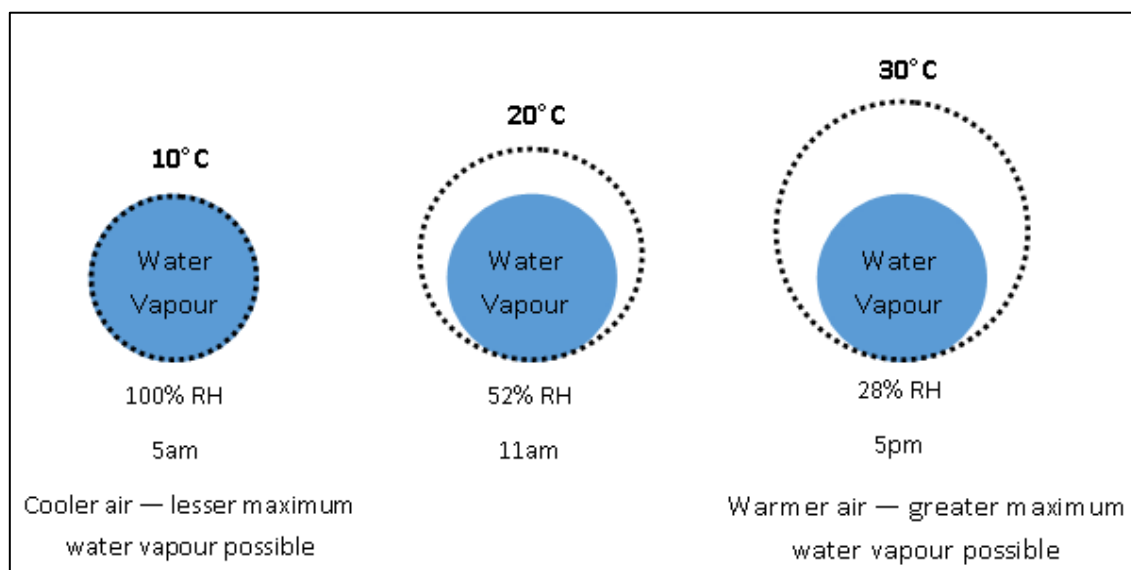


Figure 3.13 Relative humidity and maximum water vapour possible

Source: Adapted from Fresh Produce Exporters' Forum, 2016:126

3.7.1.2 Relative humidity

Relative humidity is the humidity or amount of water vapour present in the atmosphere, expressed as a percentage of the amount required for the air to be completely saturated at that temperature. Thus, the higher the relative humidity, the closer the atmosphere is to the dew point temperature. If condensation does occur as a result of temperature fluctuations, the risk of fungal decay and weight loss as well as other quality diminishing factors increases (PPECB HP02, n.d.).

Moisture loss begins the moment the fruit is harvested and as it is cumulative in nature, it is imperative to keep transpiration to a minimum. Transpiration can have serious effects on the appearance of the fruit from cosmetic and physical viewpoints as well

as on its weight and ripeness as mentioned previously and elaborated on in section 2.5.1. The goal is to find the ideal balance of the optimal low temperature that will ensure the fruit has a lower rate of respiration and sufficient relative humidity level without causing any damages to the fruit through chilling or condensation, while keeping moisture loss to a minimum. An important factor to consider during this time is the packaging of the fruit.

3.7.2 Packaging affecting temperature

The various layers of packaging materials each play different roles within the cold chain from protecting and preserving the product to allowing sufficient airflow and gas exchange and most notably, rapid and effective cooling of the fruit. In addition, the packaging must also withstand outside factors that it will be subjected to without losing its stability or integrity. These include movements such as vibrations and possible impacts during transportation, rough handling during the stuffing and destuffing of the container, the compression factor of the weight of the products when palletized and high humidity levels experienced during parts of the cold chain such as during precooling and transit (Hamburg-Sud, 2016).

When palletized, cartons of fruit are stacked on top of one another onto a wooden pallet. This unitization of the cartons onto the wooden pallet is also called a pallet and enables a larger volume of fruit to be handled faster and more easily. For efficient and effective air circulation to take place between, as well as within the cartons, there needs to be both vertical and horizontal airflow. Pre-cut ventilation holes in the cartons and bags surrounding the fruit aim to aid ventilation. These holes can only aid airflow if they are stacked in a suitable pattern for both horizontal and vertical air circulation, as both are experienced during the cold chain. Otherwise, the packaging can hinder the flow resulting in potential hot spots and even blocking off circulation entirely (Fresh Produce Exporters' Forum, 2016:128). Horizontal air flow is experienced by the pallet during the initial cooling stages where Forced Air Cooling (FAC) takes place as shown in Figure 3.14. This is where a large fan strongly blows cooled air through the pallets in a sealed cooling tunnel to lower the fruit's temperature. Vertical air flow will be experienced by the pallet when it is loaded into the reefer container as the air is blown into the container from the T-bar floor and then up through the pallet from the bottom before being circulated once again. Figure 3.14 illustrates the initial vertical airflow, while Figure 3.15 further elaborates by illustrating the vertical airflow through the

cartons. The design of the packing ventilation holes can have a major impact on the cooling efficiency, energy consumption and overall heat load experienced throughout the cold chain and especially within the container (Defraeye, Nicolai, Kirkman, Moore, van Niekerk, Verboven & Cronjé, 2016 ; Fresh Produce Exporters' Forum, 2016:128).

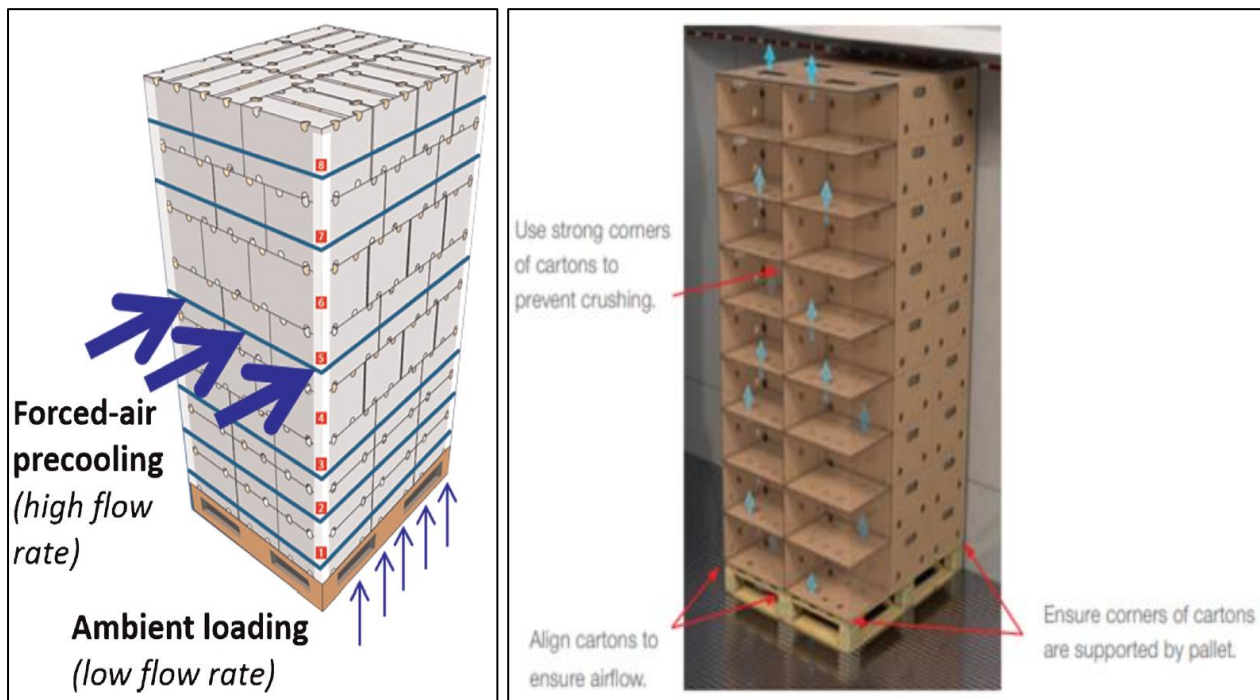


Figure 3.14 Airflow illustration of horizontal forced air-cooling, FAC, and ambient vertical airflow

Source: Defraeye, *et al.* 2016:2

Figure 3.15 Optimal airflow with packaging ventilation in stacked pallet

Source: Hamburg-Sud, 2016

3.7.3 Temperature within a container

A refrigerated container (reefer), is a container equipped with a refrigeration unit and works on a similar cooling principle to a household fridge. A reefer is capable of maintaining specified temperatures in a maximum range from approximately -35°C to 30°C depending on the type of reefer (Hamburg-Sud, 2016). As with a household fridge, a reefer container relies on an external power supply to function. However, during stages where a fixed power supply is not available, such as during trucking, a reefer can be powered independently through the use of a diesel-powered generator, known in industry as a genset.

Air in the reefer container is circulated via two fans. The air is pushed downwards where it passes through a baffle plate under the T-bar flooring before vertically ascending via the T-bar floor and continuing through the cargo. This air temperature is known as DAT. DAT stands for Delivery Air Temperature and it is the temperature of the air just prior to coming into contact with the product (PPECB HP44, n.d.). As the air circulates through the cargo, the warmer air now reaches the top of the reefer. This warmer air is circulated back towards, and then through, the refrigeration unit where the cooling process will be repeated. This warmer air is known as RAT or Return Air Temperature and is the temperature coming directly off the product (PPECB HP44, n.d.). The cargo should now be at the prescribed 'optimum temperature', which is the actual temperature of the flesh of the product (PPECB HP44, n.d.).

It is very important to note that a reefer container is not built to cool down warm or hot contents, but rather to maintain the already cooled products at a specified temperature (Fresh Produce Exporters' Forum, 2016:115). In addition, the loading of pallets into the container is also critical to ensure an adequate airflow and circulation. Airflow tends to take the path of least resistance (Hamburg-Sud, 2016). If the cartons on a pallet as well as the pallets themselves are not loaded with sufficient spaces and gaps for air to pass through, heat build-up such as respiratory heat, cannot be removed. Furthermore, if loaded incorrectly, other issues may arise such as a blockage, which could cause a restriction in airflow and result in some parts of the load to not receive sufficient air circulation. These issues could result in hot spots within the container and ultimately be detrimental to the contents of the load. Figure 3.16 and its accompanying key visually illustrates the horizontal as well as vertical airflows experienced within a reefer container.

Effective temperature control within a container is of paramount importance during the cold chain. Due to the cumulative nature of temperature breaks and the negative impacts thereof on the fruit itself, it is one of the most important contributing factors to end product fruit quality.

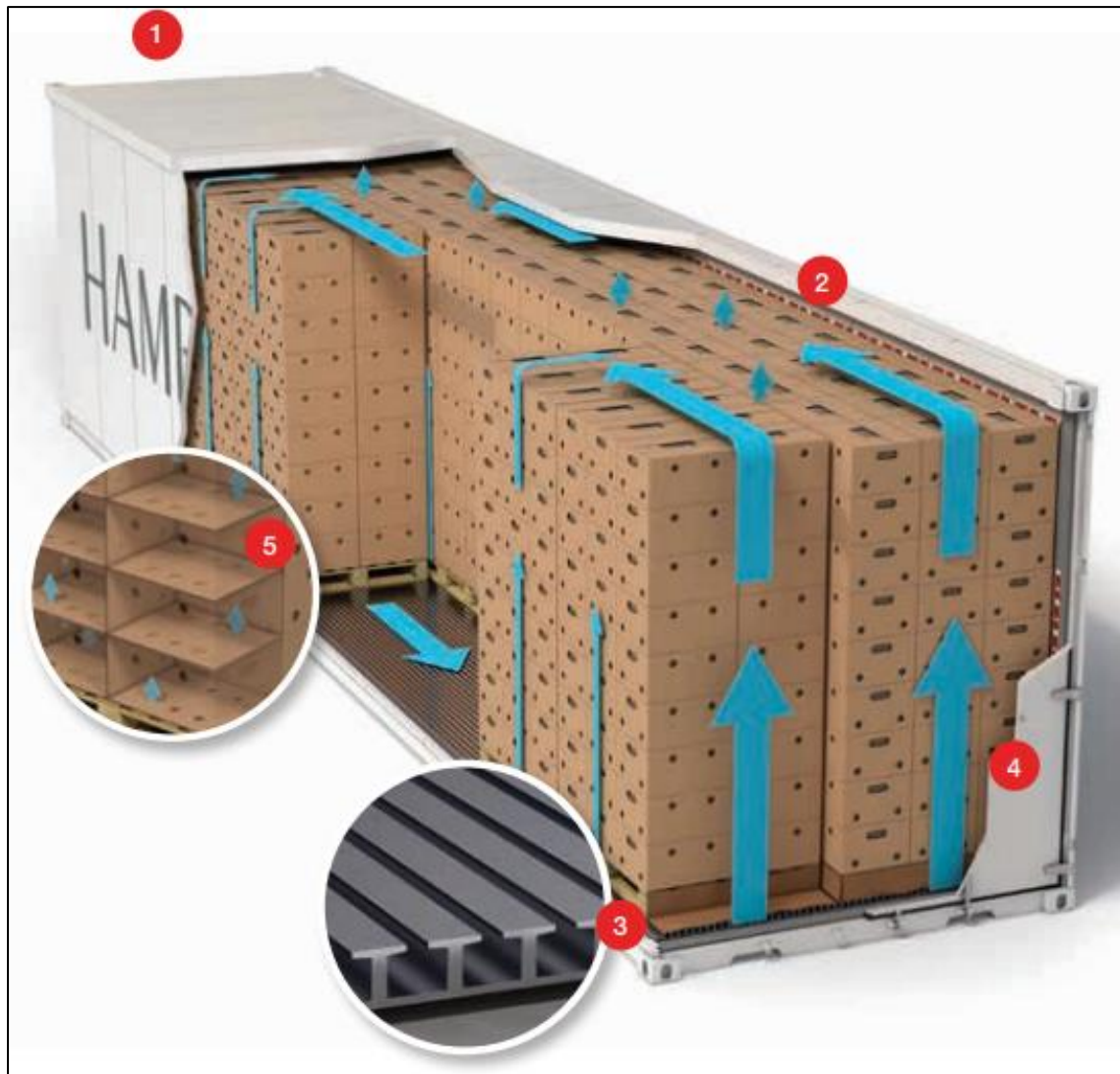


Figure 3.16 Airflow within loaded reefer container of fresh, chilled fruit

Source: Hamburg-Sud, 2016

Key	
1	Cooling unit of the reefer container.
2	Red cargo load line indicating maximum load height limitation
3	Cross section of T-bar floor of reefer container
4	Doors of the container
5	Airflow between cartons within container

3.8 Quality

The Fresh Produce Exporters' Forum define fruit quality as, "a composite of those characteristics that differentiate individual units of the product and which have significance in determining the degree of acceptability of the product by the buyer" (2013:90). It is important to note that there is a difference between fruit quality and food safety standards as well as the terms 'quality' and 'condition', which are often used interchangeably. Fruit quality, for the end consumer, is the particular and perceived experience of the fruit with regards to visual appearance and taste. This experience, however, will directly depend on the condition of the fruit at the time of consumption. Thus, the condition of the fruit will impact the consumers' experience of fruit quality. As fruit is a living organism constantly undergoing complex changes influenced by the maturation and senescence processes as well as environmental and storage conditions, the consumer's experience of fruit quality results from numerous factors and is thus, subjective and biased. On the contrary, food safety standards are objective, scientific methodologies describing technical aspects such as colour, packaging and size (Fresh Produce Exporters' Forum, 2013:64). In addition, modern, differentiating standards include aspects such as ethical trading and environmental stewardship relating to carbon footprint management, biodegradable packaging materials and water resource protection to name a few (Fresh Produce Exporters' Forum, 2013:65). Examples and explanations of some of these modern standards are elaborated on in section 2.10, International best practices in cold chain fresh fruit exports and subsection 2.10.1, Voluntary standards.

Furthermore, temperature impacts greatly on food quality. Most of the factors that can affect fruit quality, such as post-harvest microbial growth, respiration rate and relative humidity among others, can be influenced by temperature. These factors can also be accelerated as they are promoted by fluctuations in temperature. Consequently, once the temperature has begun on its downward trend, it is imperative that it must not rise, but rather remain on its downward trajectory.

Temperature plays a pivotal role in the ripening process of fruit as it effects the speed at which a fruit can ripen or begin to decay, often referred to as degradation as a result of microbial growth. This is due to fruit's perishable nature in conjunction with the fact that fruit naturally generates respiratory heat through carbohydrate conversion into energy induced by ethylene (PPECB HP02, n.d.; Silva, 2010; Fresh Produce

Exporters' Forum, 2016:53). The speed at which fruit ripens has a direct impact on the lifespan of the fruit as well as its shelf life once in store. The shelf life directly influences the fruit's ability to be sold and generate revenue for the business.

Through good temperature management, the quality of the fruit can be preserved at its optimum as concerns such as moisture loss, undesirable metabolic changes and loss of edibility due to post harvest microbial growth can be delayed and possibly entirely avoided prior to consumption. The standard of quality will determine in which class the fruit can be categorized, thus, in which markets the fruit can potentially be sold and ultimately determine the price the fruit will be sold at. A high quality standard will enable the fruit to meet specified criteria of foreign markets who are willing to import and pay a premium price as a result.

3.9 Regulatory bodies, their respective roles and exporting requirements and regulations

There are strict rules and regulations set by regulatory bodies that outline various protocols and procedures that need to be adhered to during the export cold chain from South Africa. These exporting standards must be met at each stage during the exporting process for the shipment to be successful.

3.9.1 Department of Agriculture, Forestry and Fisheries (DAFF)

The Department of Agriculture, Forestry, and Fisheries (DAFF) is a branch of the South African government. It is charged with the responsibility of supporting and overseeing the agricultural sector in addition to ensuring sufficient, safe and nutritious food can be accessed by the South African population (DAFF FAQs, n.d.). DAFF prescribes both fruit quality and food safety standards within the fruit sector. These prescribed export requirements and standards are broadly outlined in the Agricultural Products Standards Act (Fresh Produce Exporters' Forum, 2013:65). The APS Act is then further broken down into specific regulations for individual fruit kinds and their particular varieties, for example Granny Smith apples. Moreover, DAFF is solely responsible for maintaining as well as updating all standards and requirements as advances in technology and knowledge change.

3.9.2 The Perishable Products Export Control Board (PPECB)

The Perishable Products Export Control Board (PPECB) is South Africa's official perishable produce export certification agency. The PPECB was established in 1926 through a Parliamentary Act and currently operates under Act No 9 of 1983, known as

the Perishable Products Exports Control Act (de Beer, Paterson & Olivier, 2003). The State-owned, parastatal entity is involved in a number of activities across the supply chain and thus defines themselves as, “an independent service provider of quality certification and cold chain management services for producers and exporters of perishable food products” (PPECB Overview, n.d.).

In essence, the PPECB controls and regulates all perishable exports originating in South Africa. These exports have an approximate value of R20 billion per year (DAFF 2017f). Furthermore, food safety services as well as inspections are also a responsibility assigned to the PPECB by the Department of Agriculture, Forestry and Fisheries under the Agricultural Products Standards Act, No. 119 of 1990 (PPECB Overview, n.d.). Furthermore, the PPECB is also recognized and approved by the European Commission for its EU equivalent standards during inspections and was the first service provider in South Africa to receive the EUROGAP accreditation (DAFF, 2017f). This means that inspections done in South Africa are on par with inspections done in the EU and ultimately results in fewer, if any statutory inspections upon arriving at European ports of import (PPECB Overview, n.d.; Fresh Produce Exporters' Forum, 2013:65). Every country has a version of their own PPECB body with unique requirements and perishable produce treatments entering and exiting their country.

The PPECB releases a manual annually called the ‘blue book’. It details descriptions of “general procedures, loading and carrying temperature requirements for the export of perishable products from South Africa (Perishable Products Export Control Board, 2013, 2008). These standards include the handling, storage and transport aspects of perishable products. The agricultural standards addressed in the ‘blue book’ must be strictly adhered to otherwise the shipment will not get export approval and will remain in South Africa. PPECB officials are present at farms, pack houses as well as within the port terminals of South Africa.

3.10 Ports

A port terminal is an area along the coast with one or more natural or artificial harbours where ships dock and transfer passengers and/or cargo. Shipping capitalises greatly on the benefits attained through economies of scale and are a means of integration for a country into the global economy (Dwarakisha & Salima, 2015). Three ports were used during this research, namely the Port of Cape Town, the Port of Rotterdam and

the Port of London Gateway. All three ports vary in terms of age, scale, types of cargo handling capabilities and degrees of automation.

3.10.1 Port of Cape Town

The Port of Cape Town can trace its beginnings as far back as 6 April 1652 when Jan van Riebeeck arrived in the Cape and was tasked, among other things, with establishing a supplies station. The first construction of the port was a jetty, built by van Riebeeck in 1654 (World Port Source, 2005; Ingpen, 2015). Today, the Port of Cape Town has expanded into one of South Africa's busiest ports.

The Port of Cape Town currently consists out of two main cargo handling docks, namely, the Ben Schoeman Dock and the Duncan Dock, the yachting marina and lastly, the Victoria and Alfred basins as shown in Figures 3.17 and 3.18. The Ben Schoeman Dock is located on the outer perimeter and is responsible for the container terminal. According to Transnet Port Terminals (TPT), there is a 7-year planned capacity increasing project with a phase called 'The Cape Town phase 2B project'. It involves resurfacing work, the creation of a truck staging area and ancillary works, which will increase the terminal's capacity by 0.4 million TEUs, from its current 1 million TEUs to 1.4 million TEUs (Transnet Port Terminals, 2018).



Figure 3.17 Port of Cape Town

Source: Port of Cape Town, n.d.



Figure 3.18 Port of Cape Town layout

Source: Cape Town, n.d.

3.10.2 Port of Rotterdam

The Port of Rotterdam is one of the oldest ports in Europe with its origins dating back to 1283 (Port of Rotterdam, n.d.). It is also the largest port in Europe and the 10th largest in the world (Port of Rotterdam, 2018). The port is 42km long with facilities for dry, liquid and break bulk as well as containers as depicted in Figure 3.19. The port has a throughput of 469 million tons with a container throughput of 14.5 million TEU's (Port of Rotterdam, 2018).

The container terminals of the Port of Rotterdam boast 18 500 reefer connection points (Port of Rotterdam, 2018). The port is also currently investing in a 60 hectare 'Food Hub' at the entrance of the Maasvlakte (Port of Rotterdam, 2019). The centrally located hub will allow facility sharing opportunities for things such as customs, storage and transport and in turn potentially hasten time to market.

Furthermore, the port is also investing in new rail connections specifically for reefer containers. Its known as 'CoolRail' (Port of Rotterdam, 2019) and is specifically for fresh produce. The initial phase that became operational from 6 May 2019, consists

of a temperature-controlled train running between Rotterdam and Valencia three times a week.

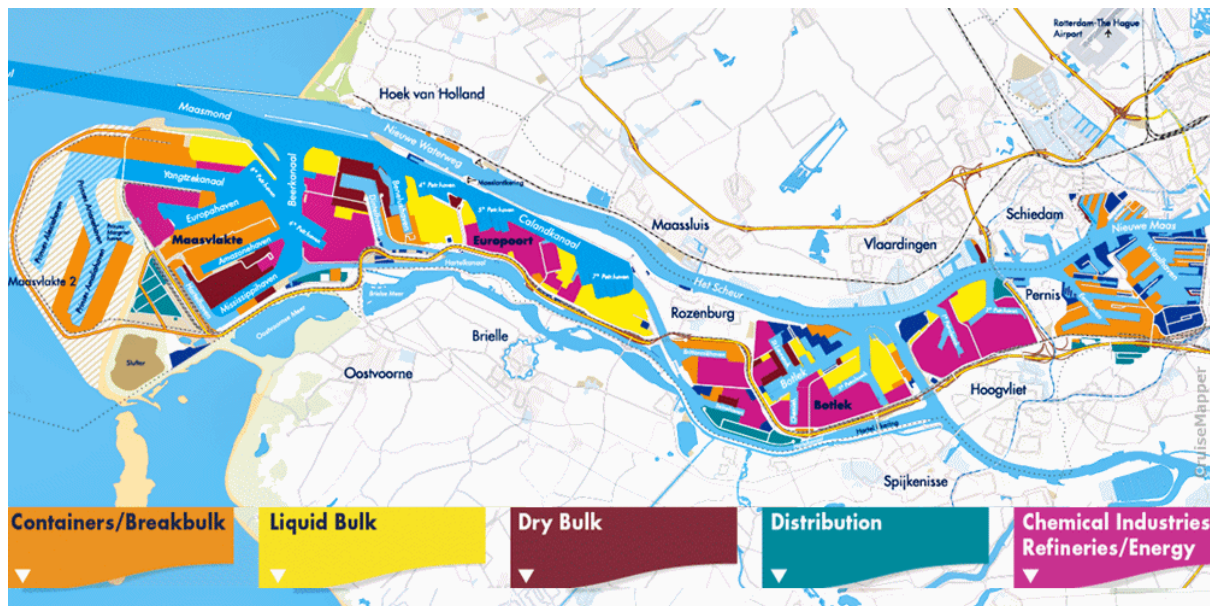


Figure 3.19 Port of Rotterdam layout

Source: Rotterdam, n.d.

3.10.3 Port of London Gateway

The Port of London Gateway is a relatively new port, which lies within the wider Port of London. The port came about as a solution to the rising demand of containers entering the Port of London and began operations on 6 November 2013 as a semi-automated, deep sea container terminal (DP World, 2018). Currently, the port only has three of its six berths completed and functional with an ultimate throughput of 3.5 million containers projected when all the berths are complete (Wainwright, 2015).

Firstly, the port is only approximately 32km away from London and is linked via road and rail (Rowlatt, 2013). Secondly, the port currently has more than 1 800 reefer points as well as a 'weather resilient, automated container stacking system' in conjunction with specialised inspection facilities and a container shunting service between the port itself and its developing Logistics Park. Regarding the developing Logistics Park, a new 107 155 sq ft multi-temperature warehouse completed construction in late March 2019 (DP World, 2019).



Figure 3.20 Port of London Gateway

Source: DP World, 2018

3.11 International best practices in cold chain fresh fruit exports

International best practices are generally accepted methodologies or techniques that deliver superior results in comparison to other methods and have thus, become the standardized manner in which that situation is handled across the world.

Best practices are used to maintain high standards of quality voluntarily via things such as benchmarking or adherence to globally accredited standards such as those provided by the International Organisation for Standardization (ISO). The function of an international standard is to 'facilitate the international coordination and unification of industrial standards' (ISO, 2018). This enables the fast tracking of many functions, including logistical functions, as all parties involved will understand exactly what is required regardless of language, currency or other infrastructural differences. The greater the uniformity is within industry, the greater benefits attained, but not limited to; ease of new and global market entrance, cost reductions through 'not reinventing the wheel' and benefits from benchmarking against industry leaders and experts.

Technological advancements in the logistics and transport industry are advancing at a rapid pace and challenging current ways of thinking within industry. With the rise of disruptive technologies such as artificial intelligence (AI), driverless trucks, blockchain and the Internet of Things (IoT), new unexplored options are becoming readily available in what is known as Logistics 4.0.

Artificial intelligence (AI) is the recreation of human intelligence in machines (Frankenfield, 2019). In essence, it is programming machines to continuously learn, adapt and problem solve, mimicking human-like intelligence, to achieve the best possible outcome. There are numerous AI applications that span all industries with everyday examples including Siri and Netflix. A logistics focussed example of AI is autonomous vehicles, more specifically, driverless trucks. Without the need for a human driver, trucks could operate non-stop as there is no need for rest time, increasing the speed and efficiency within a supply chain. Additional driverless vehicle applications could be used in terminals and warehouses such as the warehouse robots used by Amazon (Simon, 2019).

Blockchain technology can be defined as a “decentralized distributed ledger that records transactions between two parties” (Smith, 2019). Essentially, block chain is a means of record keeping that removes the need for transactions to be verified manually because each parties’ “accounting division” has access to a shared ledger for verification and consensus purposes pertaining to that specific transaction. Blockchain technology has great potential to increase transparency between supply chain partners and thus, expedite transaction times (Fortney, 2019).

The Internet of Things can be defined as, “the interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data” (Lexico, 2019). In essence, it means that every individual product, process and person can be monitored during each link in the entire supply chain in real time (Zimmerman, 2019). Benefits of the IoT include integration between systems and processes as well as giving management real time data for better decision making.

These disruptive technologies are changing traditional logistics operations and forcing businesses to adapt through what is known as Logistics 4.0 (Barreto, Amaral & Pereira, 2017). Logistics 4.0 encompasses the combined use of the newest technological advancements and methods in the logistics field to widen the scope of logistics from just transport orientated to the functional, company-wide coordination of all logistical activities across the whole supply chain (Barreto *et al*, 2017).

An example of technological advancement in the fruit industry is the ‘intelligent container’, also known as a ‘smart container’ (Smart Containers, 2018). Many shipping market leaders, such as A. P. Moller-Maersk, MSC and CMA-CGM have partnered

with Traxens, a French smart cargo monitoring and tracking service provider. Traxens provides a 'Traxens-Box' that can be permanently fitted into a typical ISO container, converting the existing container into a 'smart container'. The 'Traxens-Box' records and transmits condition and location data via 'Traxens-Net', a specifically designed mesh radio network, whereafter it is ultimately uploaded onto 'Traxens-Hub', a cloud-based data gathering platform, prior to distribution to the relevant people (Manaadiar, 2018 and Traxens, 2019). This technology allows for the upgrading of existing containers to smart containers. In addition, the technology can be used across modes with a new joint venture with Traxens and CFL, a European multimodal service provider, on rail freight wagons travelling within Europe and on the New Silk Road (Tomás, 2019). Another company has taken the smart container one step further. Smart Containers Group, a Swiss-based 'high-tech container provider' that specialises in temperature-controlled logistics, is combining all of these technologies to ultimately create a completely autonomous smart container. At present, their pharmaceutical containers division, Sky Cell, has the largest fleet of integrated, IoT sensor based, blockchain connected airfreight containers worldwide. Their smart containers boast a 0.1% temperature deviation. The company is set to venture into the perishables market with its food division, Food Guardians (Smart Containers, 2018). A further advancement is that of synchromodality.

Synchromodal logistics or synchromodality, is a new, up and coming concept in the logistics field that was pioneered in the Benelux region in western Europe (Giusti, Manerba, Bruno & Tadei, 2019:92). It encompasses a dynamic, real time modal shift of freight with the synchronization of various stakeholders' supply chains, information technologies and operations (Giusti *et al*, 2019:92 and Lemmens, Gijsbrechts & Boute, 2019:19). Benefits of synchromodality include, but are not limited to more efficient utilization of existing resources with real time information feedback that enables flexible decision making between cooperating and coordinating stakeholders. The Port of Rotterdam, part of the Benelux region, has outlined in its 2030 vision program its intentions of becoming the best 'synchromodal hub' in northwest Europe (Giusti *et al*, 2019:103). Other ports, such as the Port of Antwerp, have been investigating the use of blockchain technology to enhance the security of container collections as a facet linking to synchromodal logistics (Port of Antwerp, 2017 and Giusti *et al*, 2019:104).

3.11.1 Voluntary standards

With consumers becoming more empowered and conscious about the impacts of their consumption, there is an ever-increasing demand for specific information pertaining to the products they purchase. This information ranges from the environmental impact and preservation efforts undertaken during production of the product to its geographical origins and even social welfare and equality efforts, in addition to the standard nutritional and food safety information (Fresh Produce Exporters' Forum, 2016:248). The request for this information to become standardized is becoming increasingly important in Europe and among European consumers and can thus, not be ignored. It is important to note the difference between a regulation and a standard. The difference is found in the level of compliance and the additional implications thereof (Fresh Produce Exporters' Forum, 2016:248). A regulation is by its nature an obligatory requirement that must be met, whilst a standards' conformity is voluntary. In terms of international trade, not adhering to all stipulated regulations will result in the product not being allowed to be sold in the foreign market. In contrast, not complying with all voluntary standards will result in the product still being able to be sold in the foreign market, but the product's market share might be adversely affected. Therefore, despite the voluntary standards not being a legal requirement for exporters, a few markets have become so stringent that some of the voluntary standards available are almost a 'non-negotiable' for exporters to comply with if they wish to gain access to that market.

There are a number of international voluntary, sustainable production certification systems available as well as specified sustainable supply chain governance systems (SSCG), for certain trading partners, such as between South Africa and the European Union. There are even further SSCG's requested by individual retailers that exporters must comply with before trading can commence. The diagram in Figure 3.16 provides a visual representation of the international voluntary sustainable production certification systems available and the current SSCG's between South Africa and Europe within the fresh fruit export chain. Furthermore, the diagram illustrates the issues addressed within each SSCG as well as the number of actions it will take to address each factor.

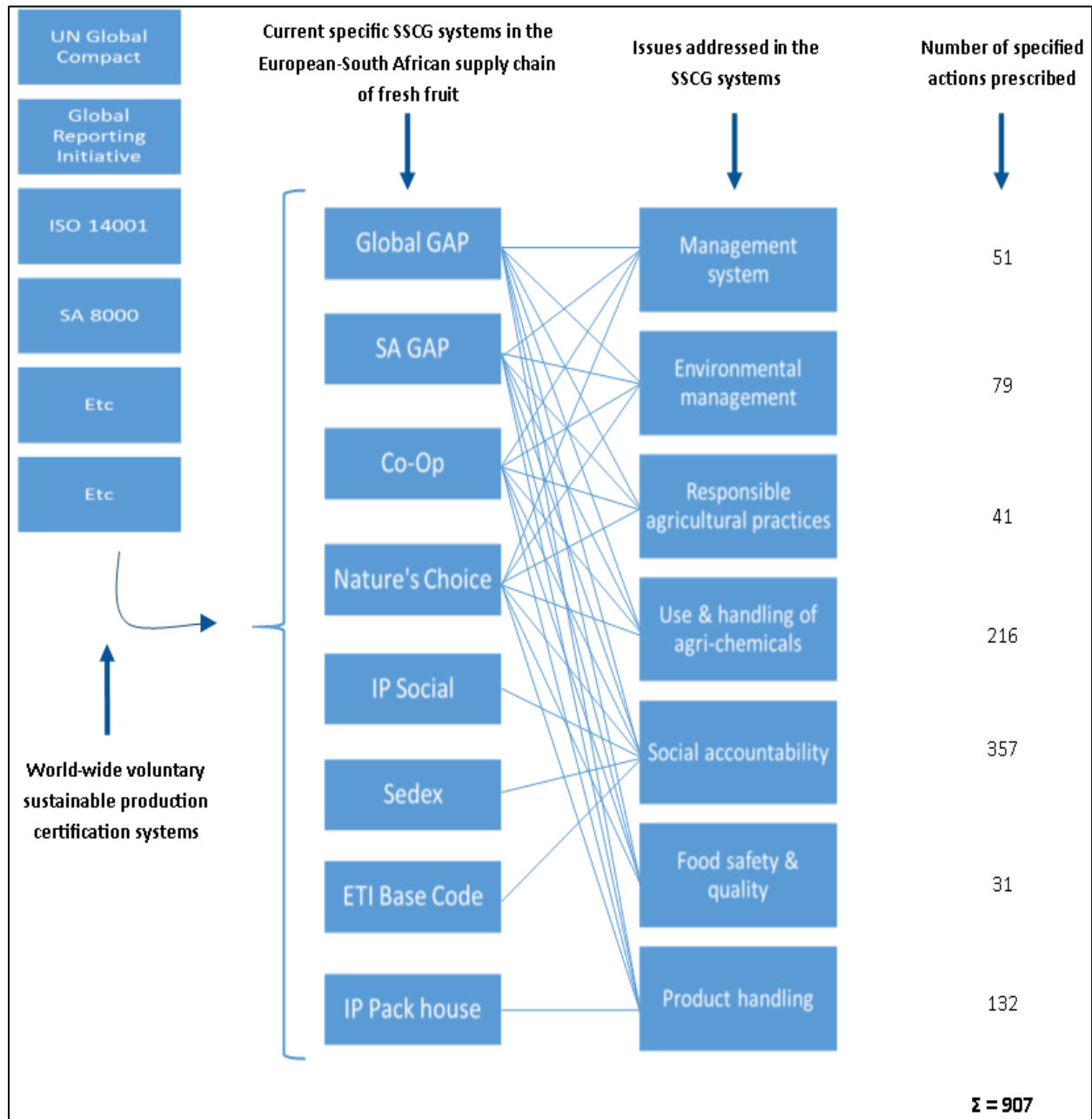


Figure 3.21 EU-SA Fresh fruit supply chain SSCG systems

Source: Adapted from Fresh Produce Exporters' Forum, 2016:249; Lancaster, 2012

Forming a part within SSCG's, there are specific standards for specific aspects that will govern conduct within that facet of the supply chain. Examples of this include social and environmental accountability, which falls under the international standard of the SA 8000 certification. The South African local industry has also taken initiative regarding this matter with the formation of SIZA, the Sustainability Initiative of South Africa. This standard has enabled South Africa's fresh fruit industry to benchmark its

ethical practices on its fruit farms and within its pack houses against global standards. The South African fresh fruit industry was the first to do so globally, achieving a nearly perfect score, and furthermore subjected SIZA to the Global Social Compliance Programme (GSCP) equivalence process (Fresh Produce Exporters' Forum, 2016:228). With the numerous voluntary standards and their respective SSCG's available, retailers in Europe and the United Kingdom have specified a myriad of demands producers must meet before trading with said retailer. Figure 3.17 shows the complex web of retailers and their corresponding demands for producers to meet.

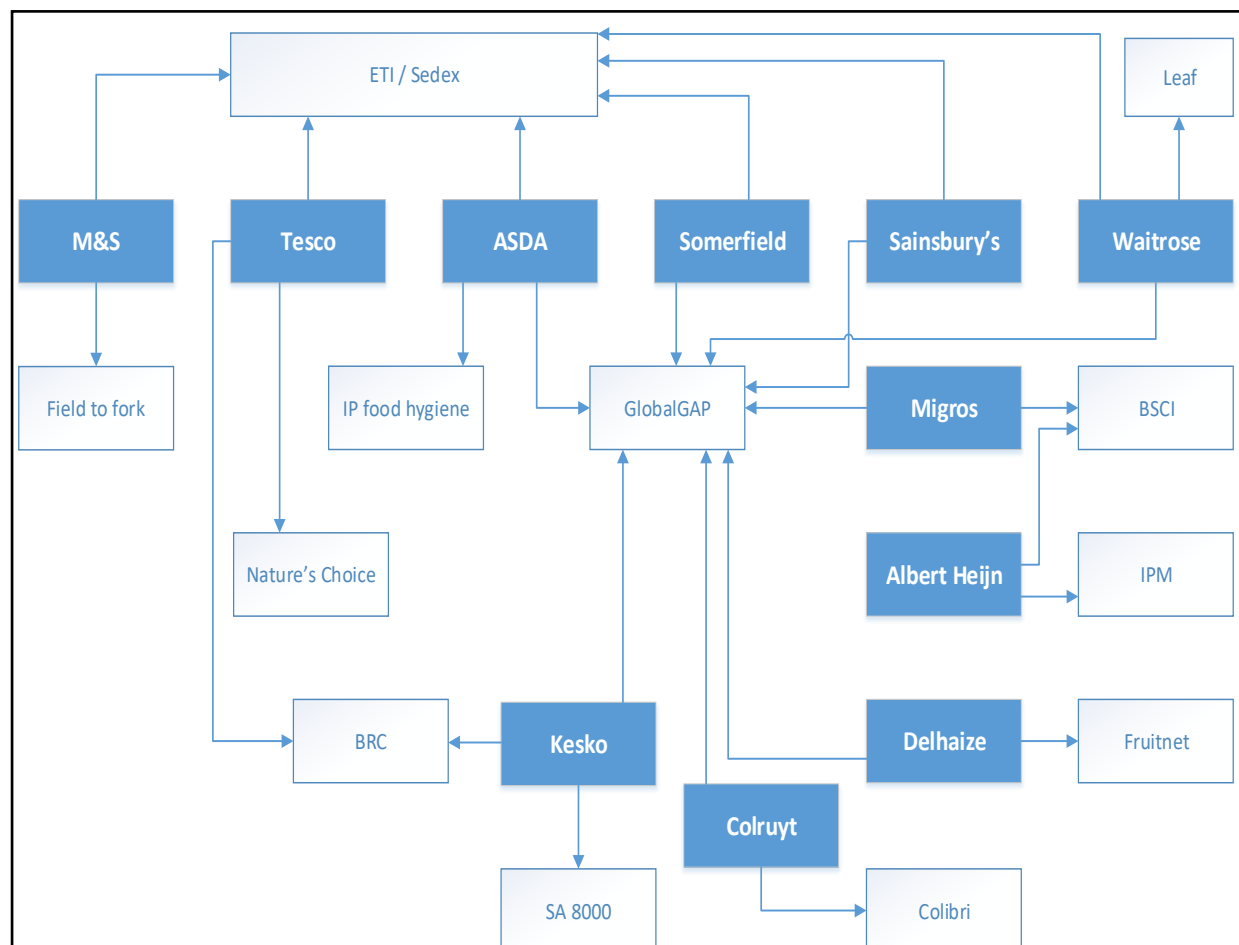


Figure 3.22 Retailer product standards demands in EU and UK

Source: Adapted from Fresh Produce Exporters' Forum. 2016:225

3.12 Previous studies and future recommendations

There have been various studies conducted pertaining to cold chains, aspects within the cold chain and the exporting of fruits. A South African deciduous fruit study done in 2012 and subsequent article in 2013, found the majority of cold chain temperature breaks occurred within the port stage of the cold chain with nearly a quarter occurring

between the times of 12:00-15:00 (Freiboth, 2012:49; Freiboth, Goedals-Gerber, Van Dyk & Dodd, 2013). The time of the majority of the breaks occurring is deeply concerning as it is the warmest time of the day. In addition, the duration of the time spent by the different fruit types within the port segment differed and was noted as well as differences in the ambient and pulp temperatures within a container.

A similar study on South African summer fruit was conducted in 2013 and subsequent article in 2015 (Haasbroek, 2013:102 ; Goedhals-Gerber *et al.*, 2015), also found the majority of the temperature breaks to occur during the warmest part of the day, between 12:00-16:00. The 2013 study narrowed down the previous findings of the 2012 study, as it found the majority of the temperature breaks to occur in the truck and reefer stacks stages of the cold chain. The study attributed possible reasons for the breaks, some of which included; loading areas situated outside in direct sunlight, loading of fruit into containers with higher than optimal pulp temperatures and trucks transporting containers without gensets (Haasbroek, 2013:104 ; Goedhals-Gerber *et al.*, 2015).

A 2014 study conducted in the Port of Cape Town also found the majority of temperature breaks to occur between 12:00-16:00 (Stander, 2014:79). The proposed reason for the breaks occurring between these times was that the majority of containers arrive at the port between 12:00 and 15:00, generating traffic. In turn, it then takes some time before the reefer containers are once again connected to a power source in conjunction with it being the warmest part of the day (Stander, 2014:80).

A study done in 2017 in the USA on time and temperature management in food cold chains linked temperature abuses to increases in food waste (Mercier, Villeneuve, Mondor, & Uysal, 2017:647). The article also discusses the benefits of a management system that is based on 'time-temperature measurements' to reduce food waste, increase food safety and make more accurate forecasts on operating expenses and capital investments (Mercier, *et al.*, 2017:663)

A 2019 study investigating food waste with particular focus on food quality and new technological advancements, such as the internet of things, showed the potential benefits of monitoring real-time shelf life (Joubert, 2019). The concept of smart technologies is still very new and expensive in South Africa with many stakeholders

still sceptical. However, a basic implementation and activities change in a strawberry supply chain was shown to lower the total food waste by 71% (Joubert, 2019).

Future recommendations would be to link a supply chain with its environmental impact and sustainability at the various stages along the entire chain. South Africa's fruit and wine industry has created an initiative known as the 'Confronting Climate Change' (CCC). This initiative was developed as a carbon foot printing project consisting of three phases; doing an audit of the current emissions, developing a comprehensive strategy including clear goals and costs and lastly an implementation plan (IPW, 2009). Other pre-harvest factors that could be investigated are standards relating to alternative pesticides. Natural methods are cleaner, environmentally friendlier and in some cases, even cheaper, as it requires less labour and voids expenditure on poisons. Examples could include investigating the viability of IPM more extensively.

4 Observations

4.1 Introduction

Part of the primary research was done through observations of the three fruit types during various stages of the cold chain. Observations were conducted in South Africa at the farms, pack houses, cold stores and the Cape Town Container Terminal. Further first hand observations were also conducted in Europe at the Port of Rotterdam and the final cold store.

An additional and important output of this section was the development of timelines for the individual containers.

4.2 Farms

The farms were the starting point for all three cold chains, however, the pome fruits starting point for this research was the pack house. Primary observations at the farms were only applicable to the table grapes section of the research. There were three farms involved during the temperature trials, namely, Farm A, Farm B and Farm C. The farms were all situated in the Hex River Valley region of the Western Cape. Figure 4.1 depicts the table grapes being harvested by hand in the vineyards and Figure 4.2 depicts the full table grape crates being off loaded at the pack house after their collection from within the vineyards via tractor.

While on the farms, informal interviews were conducted with various role players including the farmers, farm workers, for example those harvesting and those working in the pack house, a PPECB representative and Company X representatives. This assisted in fully comprehending the processes involved during this stage.



Figure 4.1 Harvesting of table grapes

Source: Authors own



Figure 4.2 Crates transported to pack house

Source: Authors own

4.3 Pack houses

For the pome fruit, both the pack houses for apples and pears were located in the Western Cape. Both the apples and pears were removed from cold storage and proceeded to move, via an automated sorter, through the pack house via a water bath. This process as well as the machinery used is depicted in Figures 4.3, 4.4 and 4.5. Once the pome fruits had been sorted via size and all defective fruits removed, they were packed onto trays, sometimes labelled, and stacked into cartons. Figure 4.8 depicts completed apple trays. When the packed cartons reached the end of the line, they were stacked to form pallets. It was at this point that individual cartons were probed concurrently while the pallets were under construction. Once the pallets were complete, they were placed in a staging area during which they were strapped, inspected and ready to be moved to the cold store.



Figure 4.3 Automated sorter

Source: Authors own

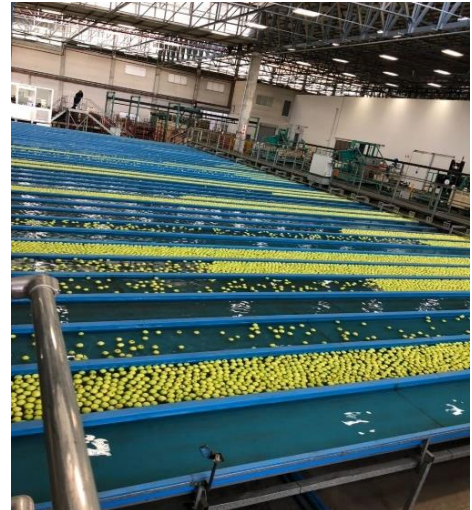


Figure 4.4 Lanes of sorted apples

Source: Authors own



Figure 4.5 Automated sorter with lanes

Source: Authors own

The researcher witnessed the harvesting and transport of the table grapes from the vineyards to the pack houses, which were all on the site of the table grape farms as shown in Figures 4.1 and 4.2. The pack houses were cooled to approximately 22°C to begin field heat removal. The journey of the table grapes through the pack house was observed, including the trimming, weighing and packing of the punnets. Depictions of the process are shown in Figures 4.6 and 4.7. It was at this point where the temperature monitoring devices were inserted. Hereafter, the cartons were packed and sent towards the end of the line where the pallets were stacked. While a full truck load of pallets was still being built, the completed pallets were moved to a cool staging

area where they were weighed, strapped and certified before being transported to the cold stores.



Figure 4.6 Hand trimming

Source: Authors own



Figure 4.7 Sorting table

Source: Authors own



Figure 4.8 Apple trays

Source: Authors own

4.4 Cold stores

The pome fruits pack houses had cold stores on site. Once the pallets had undergone all the required steps, they were transported to the cold stores to lower their temperatures to protocol temperature of -0.55°C prior to loading. The pallets remain in the cold stores until a loading instruction is received, whereafter the specific pallets are removed from the cold stores, staged and then loaded into the reefer containers. When the reefer containers arrived at the pack house, a PPECB inspection tag that sealed the container, was clipped as shown in Figure 4.9. After loading, the reefer container is sealed and a blue PPECB tag is used. The reefer containers are then switched on and transported to the Port of Cape Town. Figure 4.10 depicts a container with probed pallets being loaded.



Figure 4.9 PPECB container inspection tag

Source: Authors own



Figure 4.10 Container loading of probed pallets

Source: Authors own

For the table grapes, Farms A and C used a local cold store, Cold store A while Farm B transported their pallets via refrigerated vehicle to Cold store B. Once the table grape pallets arrive at the respective cold stores, they enter the FAC tunnels, as shown in Figures 4.11 and 4.12, to lower their temperatures to protocol temperature of -0.55°C . Once their temperatures have decreased sufficiently, the pallets are removed and placed into cold storage to await the specified loading instructions. When the instructions are received, the pallets are removed from the cold stores, staged and then loaded into reefer containers bound for the Port of Cape Town.



Figure 4.11 Forced Air Cooling (FAC) tunnels

Source: Authors own

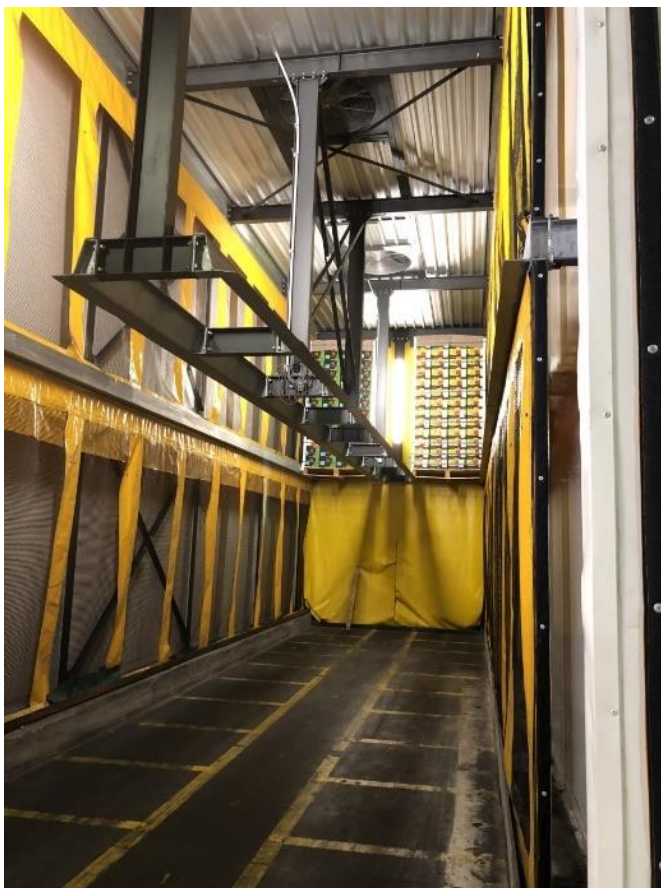


Figure 4.12 Individual FAC tunnel

Source: Authors own

4.5 Port of export

All of the fruit temperature trials containers used in this research left South Africa from the Port of Cape Town and thus, used the Cape Town Container Terminal as depicted in Figure 4.13. The opportunity of a site visit into the industrial, working side of the port was granted to the researcher. The flow of the reefer containers from the stacks, through the port and loaded onto a vessel was observed.

It was noted that the standard procedure regarding the reefer stacks for a specific vessel will usually close two days prior to that vessel's time of arrival at the port. An additional note made was the wind delays experienced by the port, which can often delay vessels for days, especially during the windy season at the start of the year. This phenomenon was seen in two of the table grape containers that remained in the terminal for approximately eight days as a result of wind delays.

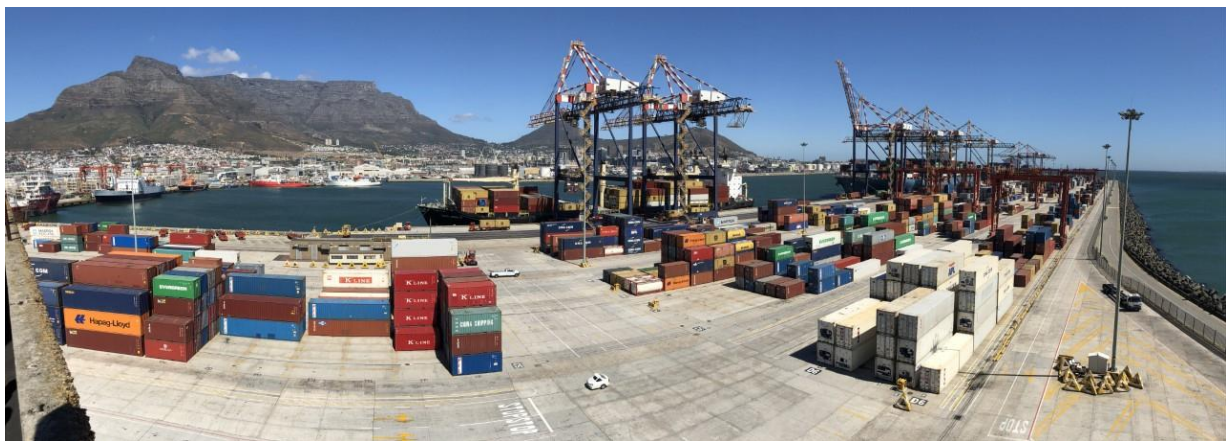


Figure 4.13 Part of Cape Town Container Terminal

Source: Authors own

4.6 Port of import and cold stores

The pome fruits were sent to the Port of Rotterdam, NL and then transported within the port to Cold store 3. Figure 4.14 shows a barge being unloaded in the Port of Rotterdam. Figures 4.15 and 4.16 depict the unloading of a temperature trial container and the staging of its pallets prior to device retrieval at Cold store 3.

The table grapes were sent to the Port of London Gateway, UK and then via truck to Cold store 1. This was not observed in person by the researcher.



Figure 4.14 Barge being unloaded in Port of Rotterdam

Source: Authors own



Figure 4.15 Unloading of pallets in Cold store 3

Source: Authors own



Figure 4.16 Staged pallets prior to inspection

Source: Authors own

5 Data Analysis

5.1 Introduction

The quantitative data gathered for this study was collected through the means of temperature trials executed during 2018. This chapter discusses and explains the data analysis approach taken as well as container journeys followed per fruit kind.

5.2 Data analysis approach

The temperature trials conducted for this research consisted of 504 temperature monitoring devices, namely iButtons® and TempTales®, inserted into the top, middle and bottom layers of six pallets per container, positioned in the front, middle and back sections within the container, for 24 reefer containers. The pallets' positions within a container are marked with a red cross as shown in Figure 5.1. The probes were placed on the three vertical layers of a pallet to determine whether there were detrimental temperature variations within a single pallet. The probed pallets were then placed in the front, middle and back of a container to see if pallet position within a container impacts temperature. The position of the probes as well as the probed pallets gave the study both a vertical and horizontal dimension.



Figure 5.1 Pallet positions within container

Source: Taljaard, 2018

The temperature data was recorded in two ways, firstly, the internal pulp temperatures of the fruits and secondly, the ambient air temperatures that surrounded the fruits. For the pome fruit trials, pulp temperature monitoring devices called iButtons® were used. In the table grape trials, however, a TempTale® 4 steel probe was used to skewer several berries for a more accurate pulp temperature reading as individual grape berries are too small to house an iButton®. The ambient temperatures in both the pome fruit and table grape trials were measured through the use of various TempTale® devices. There were four types of TempTale® devices used, namely the RFID enabled

TempTale[®], TempTale[®] 4, TempTale[®] 4 USB and TempTale[®] 4 Probe. There were 216 temperature monitoring devices used for the table grape trials and 288 temperature monitoring devices used for the pome fruit trials respectively. The table grape trial devices were subdivided into 24 pulp temperature monitoring devices and 192 ambient temperature monitoring devices. The pome fruit trial devices were subdivided into 108 pulp temperature monitoring devices and 36 ambient temperature monitoring devices for both apples and pears respectively. All the temperature monitoring devices were inserted at the farms and pack houses in the Western Cape prior to the fruits being loaded into containers and continuing on their respective export journeys.

After all the containers had arrived at their final destinations in the UK and the Netherlands, the devices were removed and data was extracted in two ways. The TempTale[®] data was either automatically uploaded or was extracted in Rotterdam and loaded onto a cloud-based system called *ColdStream[®]*, whereafter it could be accessed via a programme with a password and internet connection. The iButtons[®], however, had to be couriered back to South Africa and the data manually extracted and uploaded onto another system called *Cold Chain Thermo Dynamics*. Once all the data had been loaded onto their respective systems, it was downloaded and combined per container using Microsoft Excel. The majority of the pome fruit containers ran on 30-minute measuring intervals, while some ambient devices ran on a 45-minute measuring interval. In such cases, the data was then manipulated to reflect a 90-minute measuring interval to still adhere to the definition of a temperature break as earlier defined in Chapter 3, as well as continue the uniformity and comparability of the containers.

From the 504 temperature monitoring devices sent to the UK and the Netherlands, 414, or 82%, of the temperature monitoring devices' data was received. Table 5.1 provides a detailed breakdown of the number and type of devices inserted and retrieved per fruit kind. One container worth of devices from each trial was unable to be retrieved. This was due to it being sent further along in the cold chain and then lost or the retailers were unwilling to retrieve the devices. In addition, both apples and pears lost the information recorded on nine devices each with the table grape trials losing the information recorded on six devices. These devices were either lost, malfunctioned or could not be read out.

Table 5:1 Number of Inserted vs retrieved temperature monitoring devices

Temperature monitoring devices inserted vs retrieved per fruit kind								
	iButtons® (pulp)		Temptale® 4 Probe (pulp)		TempTale® (ambient) (RFID,USB, 4)		Total	
	Inserted	Retrieved	Inserted	Retrieved	Inserted	Retrieved	Inserted	Retrieved
Table grapes	0	0	24	20	192	172	216	192
Apples	108	81	0	0	36	30	144	111
Pears	108	83	0	0	36	28	144	111
TOTAL	216	164	24	20	264	230	504	414

After the initial data was captured in Excel spreadsheets, initial time series line graphs were plotted and analysis was done using a statistical programme called *Statistica*. This was done with the assistance of a statistical expert and Professor from the Centre for Statistical Consultation (CSC) at Stellenbosch University. This initial analysis assisted in the identification of container temperature breaks, which were established if there were two or more devices that registered a temperature break simultaneously. This gave an overview of the containers' holistic temperature profile along its entire supply chain journey. Thereafter, the data underwent further preparation and additional cleaning through the use of a programme called *Tableau Prep*. Subsequently, additional and more in-depth analysis and data visualisation was done through another programme called *Tableau*. *Tableau* enabled the temperature breaks to be analysed on a device level. It was important to distinguish the difference as a single container break could be registered, per device level, up to 24 times.

Table 5.2 provides a summarized table of the variables used in the data analysis. In addition, the stages of the cold chain were also grouped during parts of the analysis. The pome fruits trials were grouped into four sections, namely, SA Leg, Sea Leg, NL Port and NL Transport. The table grape trials were grouped into five sections, namely, SA Farms, SA Transport, Sea Leg, UK Port and UK Transport. The stages within each grouping as well as a description of the individual stage are provided in Table 5.3 and Table 5.4.

Table 5:2: Variables summary

Variables	Description	Example
Date	Actual date and time of the temperature measurements	01/05/2018 07:29:01
Time	Time interval measured in hours, minutes and seconds, but coded in whole numbers.	1 i.e. (Time interval 1)
Days	24 hour time period as from time interval 1	
Day#	Actual 24 hour period of a calendar day	
Logger name	Indicates the: <ul style="list-style-type: none"> Side of container (left / right when standing at container door looking into container) Pulp or ambient logger Pallet position within container (front, middle, back) Vertical position within pallet (top, middle or bottom) 	L1PulpMiddle = L = Left side 1 = 1 st pallet Pulp = Pulp logger Middle= middle carton
Temperature	The temperature recorded by the loggers for the corresponding date and time.	1.221°C
Temperature spike	A temperature spike occurs if the definition of a temperature break is met, but for less than 90 minutes. If the temperature is 2°C or higher or if the temperature is -1.5°C (or -1°C for pears) or colder for one time interval & temperature recording, a temperature spike has occurred.	4.905 °C
Temperature break	A temperature break occurs if the definition of a temperature break is met for the full 90 minutes or longer. If the temperature is 2°C or higher or if the temperature is -1.5°C (or -1°C for pears) or colder for three consecutive time intervals & temperature recordings, a temperature break has occurred.	3.650°C 4.215°C 4.905°C

Table 5:3: Pome fruit cold chain stages

Stage	Description	Section
Pack house and Cold Store	Fruit is removed from cold storage and placed onto a production line by means of wet dumping. Goes through entire pack house journey, is probed, palletized and placed into cold store prior to container loading.	SA Leg
Trucking to port of export	Begins with loaded containers weight-out time at the pack house and ends just prior to gate-in time at the port of export.	SA Leg
Port of export	Starts with gate-in time at the port of export and concludes when container is loaded on board the vessel. This includes when the containers were placed into the reefer stacks.	SA Leg
On board vessel at port of export	Begins when the container is loaded on board the vessel just prior to the ships actual time of departure (ATD).	Sea Leg
Sea leg	Vessel's ATD until its actual time of arrival (ATA) at port of import.	Sea Leg
On board vessel at port of import	From the vessel's ATA at the port of import until the point prior to the container being off-loaded.	Sea Leg
Port of import	From the point of the container being off-loaded from the vessel, until it was either placed onto a barge or loaded onto a truck prior to gate-out.	NL Port
*Barged	Phase begins if the container was loaded onto a barge after being off-loaded from the vessel and ends when the container is off-loaded from the barge.	NL Port
*Port of import post barge	Begins if the container was barged and then off-loaded from the barge and concludes prior to when it is loaded onto a truck trailer.	NL Port

Trucking to cold store	Begins with the gate-out time when the container is placed onto a trailer and trucked to the cold store facility where it concludes with the cold store arrival time.	NL Transport
Cold store wait	This is the possible delay from when the container arrives at the cold store prior to it being attached to a dock and destuffed.	NL Transport
Destuffed and cold store intake	This stage begins when the container is attached to a dock and destuffed until the time the devices were collected.	NL Transport

Table 5:4: Table grapes cold chain stages

Stage	Description	Section
Pack house	Fruit enters pack house directly after harvest in crates and is placed on conveyer belt ready to be pulled by a worker onto a workstation. Fruit is then trimmed, packed into punnets and placed into a carton.	SA Farms
Cold Store	Pallets are transported to a cold store where forced air cooling (FAC) takes place and then moved to cold storage prior to staging.	SA Farms
Loading in container	Pallets are moved from cold storage via forklifts, staged and then loaded into a container. Stage concludes with the truck's gate-out time from the cold store.	SA Farms
Trucking to port of export	Begins with loaded containers weight-out time at the cold store and ends just prior to gate-in time at the port of export.	SA Transport
Port of export	Starts with gate-in time at the port of export and concludes when container is loaded on board the vessel. This includes when the containers were placed into the stacks.	SA Transport
On board vessel at port of export	Begins when the container is loaded on board the vessel just prior to the ship's actual time of departure (ATD).	Sea Leg
Sea leg	Vessel's ATD until its actual time of arrival (ATA) at the port of import.	Sea Leg
On board vessel at port of import	From the vessel's ATA at the port of import until the point prior to the container being off-loaded.	Sea Leg
Port of import	From the point of the container being off-loaded from the vessel, until it was loaded onto a truck prior to gate-out.	UK Transport
Trucking to cold store	Begins with the gate-out time when the container is placed onto a trailer and trucked to the cold store facility where it concludes with the cold store arrival time.	UK Transport
Cold store wait	This is the possible delay from when the container arrives at the cold store prior to it being attached to a dock and destuffed.	UK Transport

Destuffed and cold store intake	This stage begins when the container is attached to a dock and destuffed until the time the devices were collected.	UK Transport
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5.3 Pome fruit data collection

Both apples and pears followed an identical probing procedure when the temperature trials were conducted. The pulp temperatures of the fruits were measured, via the iButton[®] temperature monitoring device, through its insertion directly into the fruit's flesh. This was done by making a small, square incision with a knife into the side of the apple or pear where a clearly labelled iButton[®] temperature monitoring device was inserted as shown in Figure 5.2. The iButton[®] was then capped with part of the apple or pear that was cut away during the initial incision and secured tightly with brightly coloured duct tape. The tape served two purposes, primarily to ensure that the iButton[®] stayed in place within the fruit and did not fall out during transit as well as to make the probed fruit easily identifiable during the retrieval process. The probed fruits were then placed into selected cartons and if an ambient temperature monitoring device was also placed into the carton, an adjacent apple or pear was removed to ensure no damage could be caused to adjacent fruit, such as bruising. This can be seen in Figure 5.3. The selected cartons were brightly labelled with neon yellow stickers on all four sides of the carton and then palletized. The pallet was also labelled with large yellow stickers as seen in Figure 5.4. The probed cartons were placed on the top, middle and bottom layers of the pallet, which were the first, thirteenth and twenty seventh layers, of the same selected corner of the pallet. The same pallet corner was selected to make the retrieval of the devices less laborious.

It should be noted that there was a pulp temperature monitoring device in the top, middle and bottom layers of each probed pallet, while there was only one ambient temperature monitoring device placed in the top carton of each probed pallet. This was due to a limited number of ambient temperature monitoring devices being available. Thus, one probed pallet contained three iButtons[®] located in the top, middle and bottom cartons as well as one TempTale[®] located in the top carton. One container had six probed pallets and therefore, a total of 18 pulp temperature monitoring devices and six ambient temperature monitoring devices.

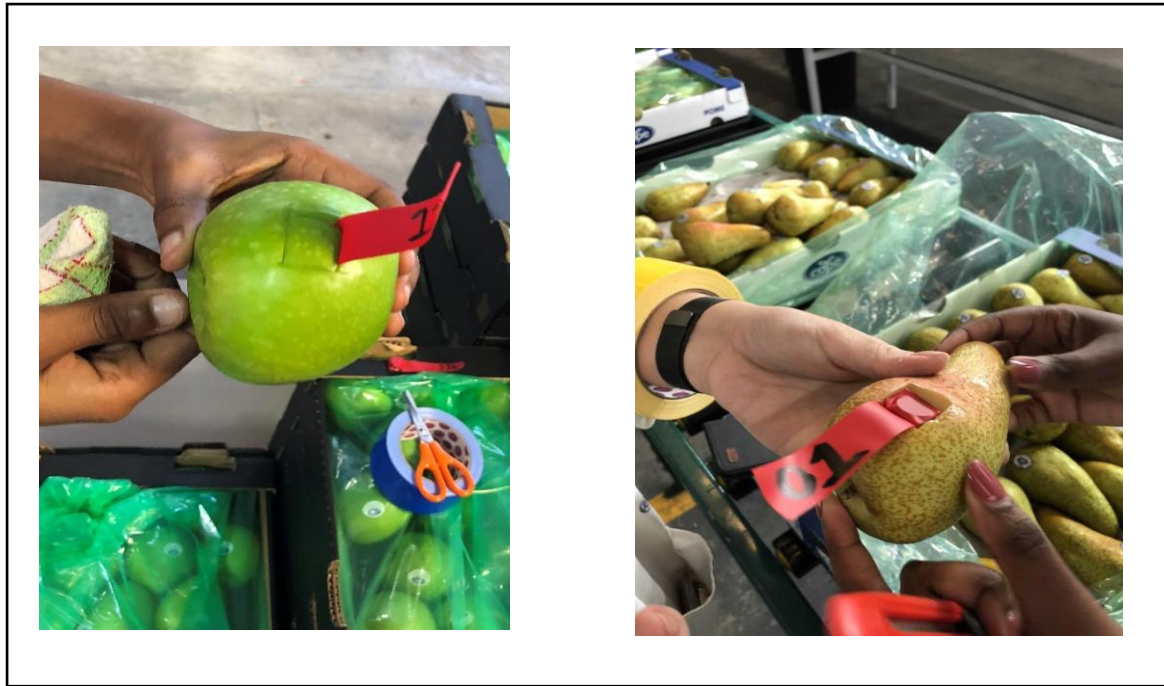


Figure 5.2 Initial apple and pear probing incision with insulation tape covered iButton®

Source: Authors own



Figure 5.3 Pulp and ambient probed pome fruit cartons

Source: Authors own

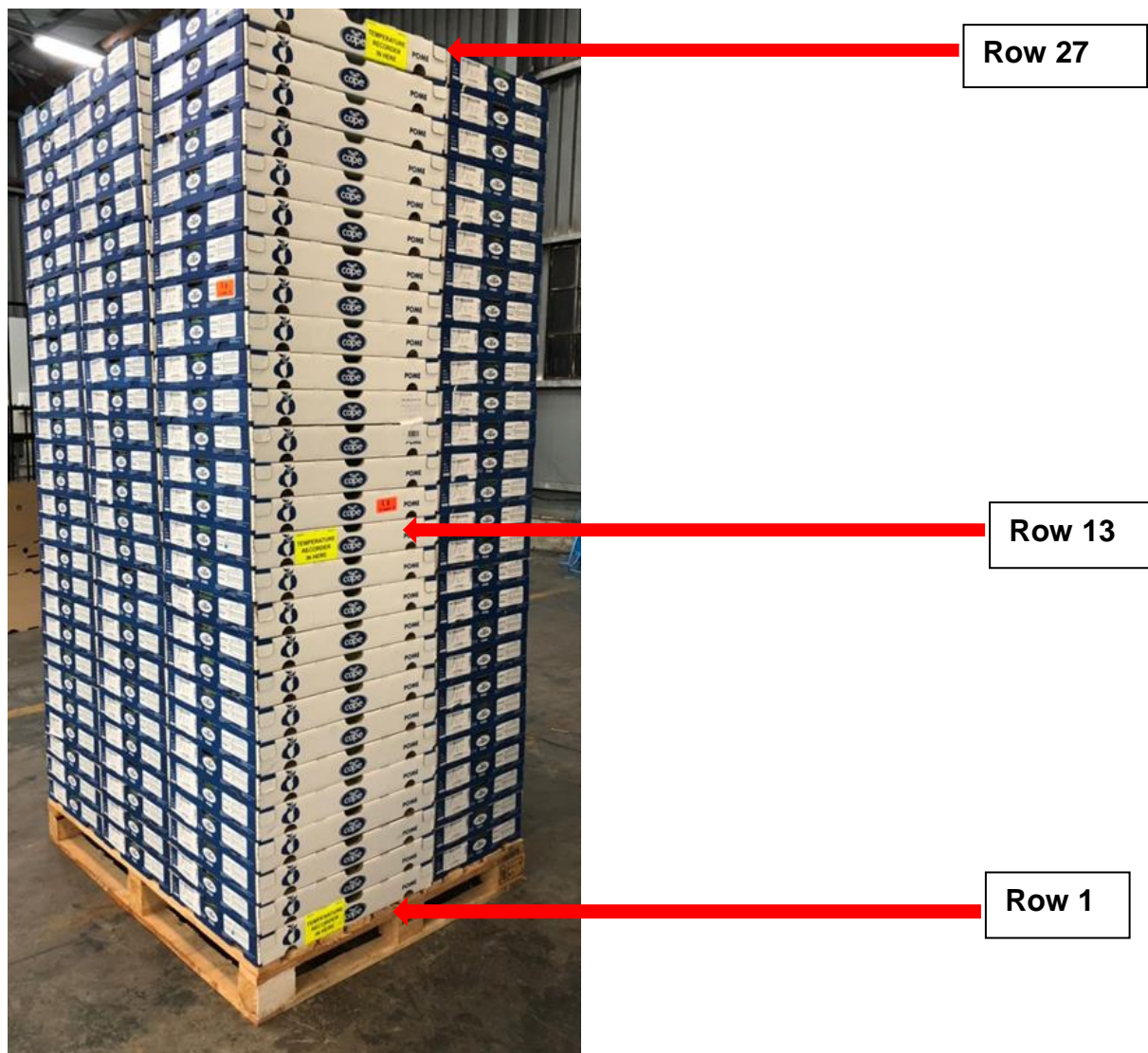


Figure 5.4 Palletization of probed pome fruit cartons with all identification stickers

Source: Authors own

5.3.1 Pack house and cold store facilities

Pack house A and Pack house B are collective pack house facilities with dual functionality as both a pack house and cold store. This is because many farmers from the surrounding areas deliver their harvest to the centralised pack house facility to create larger volumes of fruit that meet export criteria, such as exportable sized and classed fruit. As the fruit enters the pack house and gets drenched, fruit from various farmers can be mixed during the sorting and/or storing process for various reasons. Thus, it was not possible to commence the trials at the start of the apple or pear supply chains, while the fruit was still on the farms. In order to ensure that all probed pears

went to the Netherlands, the trials began in the pack houses where specified volumes of fruit had already been designated by Company X to the Netherlands.

Both apples and pears were probed once they had already gone through the pack house and were ready to be palletized. This involved the fruit being removed from cold storage, placed into a water bath and moved throughout the pack house. It should be noted that the apples came out of long-term cold storage under controlled atmospheric conditions. Once the pome fruits had travelled via the water bath through the pack house, they were then placed onto sorting tables where the fruit was handled by workers before being placed into cartons. Hereafter, it was sent via a roller conveyer belt to a table for a final quality control check before being palletized. It was at this point where the apples and pears were probed.

5.3.2 Data analysis

It is important to note that the time frames used during the analysis of all the pome fruit data corresponds to a South African time zone. In addition, the final cold store in the supply chains has been coded simply as cold store. This is due to the fact that the first stage of both the apple and pear cold chains has a combined code of 'pack house and cold store' as both Pack house A and B performed both functions as single facility. In addition, the final cold store was the same facility used in both the apple and the pear temperature trials. It is important to highlight that despite the coding, the final cold store functions more as a distribution centre. This is because the cold store not only performs the function of a warehouse by storing the fruit under cooling conditions in individual pallets, but also performs value added services. These include services such as order mixing, cross docking and even repackaging, if requested by retailers.

Furthermore, after the initial analysis and with the use of *Statistica's* time series line graphs drawn per container, a few anomalies were found. These included examples such as ambient temperature readings that spiked and remained at very high temperatures, but with little to no effect on pulp temperature readings within the same container. This was particularly prevalent in the pear temperature trials. An industry expert was consulted with the findings whereafter it was concluded to be a device malfunction. Moreover, the high prevalence in the pear trials was due to the devices being sequential and thus, all experienced similar problems in and around the same time. The graphs in Figure 5.5 illustrate this problem as four ambient devices'

temperatures spiked during the sea leg, but the effects of this drastic increase in temperature did not transpire in the pulp temperature readings.

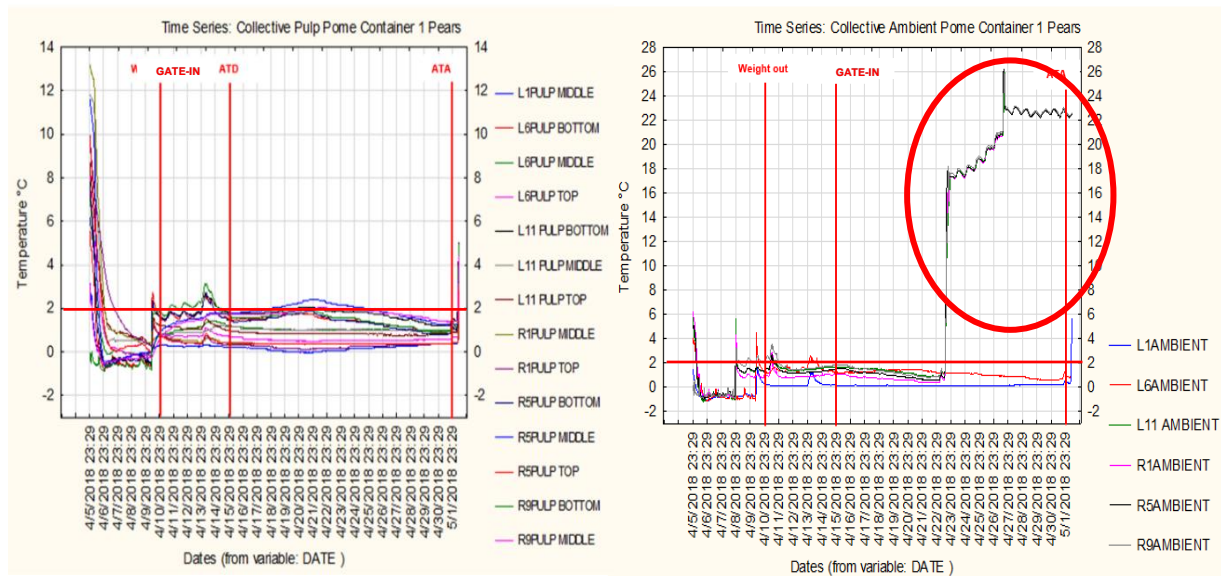


Figure 5.5 Time series line graphs of pulp & ambient temperature profiles of pears container one with anomaly

Lastly, it should be noted that due to the subjective nature of precisely when a temperature device's readings were due to a temperature break or as a result of the device malfunctioning, the number of device temperature breaks was slightly skewed. This was only really a factor in the pear trials as the number of devices that malfunctioned in pear trials was relatively higher than the rest, but still small with nine devices malfunctioning in total.

In addition, when calculating the descriptive statistics in later analyses using *Tableau*, it was possible to exclude the anomalies from the calculations. The changes were, however, marginal as illustrated in Table 5.5.

Furthermore, when graphically depicting the data, the software used could not exclude a portion of a logger's dataset, it would have to exclude the entire dataset of the logger. This would result in large amounts of valuable and usable data to be lost and so it was decided against. Table 5.5 illustrates the marginal differences, which added to reasons for not excluding loggers when graphically depicting the data, but rather just highlighting the faulty ones.

Table 5:5 Descriptive statistics with and without malfunctions

With malfunctions			Without malfunctions	
APPLES				
	Pulp	Ambient	Pulp	Ambient
Max	21.37	17.16	13.54	14.88
Min	-0.8	-1.32	-0.8	-1.32
Median	0.54	0.36	0.54	0.36
PEARS				
	Pulp	Ambient	Pulp	Ambient
Max	13.22	17.46	13.22	17.46
Min	-0.67	-1.44	-0.67	-1.44
Median	0.66	0.59	0.66	0.44
TABLE GRAPES				
	Pulp	Ambient	Pulp	Ambient
Max	29.03	28.09	29.03	28.09
Min	-1.06	-1.09	-1.06	-1.09
Median	0.08	0.09	0.08	0.09

5.4 Apples

Apples were the second of the pome fruit trials to be conducted. The trials commenced on 3 May 2018 and concluded on 4 July 2018. Six containers, namely containers seven to twelve, were probed. Two of those containers contained apples of the Granny Smith variety and the remaining four consisted of the Cripps Pink variety. Containers eleven and twelve used Shipping line Y while containers seven to ten used Shipping line Z. All of the apple containers were exported from South Africa through the Port of Cape Town and entered Europe through the Port of Rotterdam, The Netherlands. Container seven was not retrieved in its entirety.

5.4.1 Apples container journeys

The apples used in the trials entered Pack house B between 26 April 2018 and 04 July 2018 and were predominantly placed under controlled atmosphere cold storage. The containers were probed between 03 May 2018 and 04 July 2018, whereafter the probed cartons were palletized and moved into a holding room to await a final inspection and labelling before being moved into a cold store prior to being loaded into a refrigerated container. The pallets spent between approximately 4 days 21 hours and 15 minutes to 13 days and 40 minutes in the cold store prior to container loading. The containers weight-out dates and times at pack house B were individually recorded,

whereafter, the containers were trucked to the Port of Cape Town. The most direct journey is approximately 64km, which would take a truck approximately 1.5 to 2 hours to complete. The average trucking time of the containers was 02 hours 48 minutes from Pack house B to the Port of Cape Town. This was due to three main factors. Firstly, this journey involves the mandatory use of a weigh bridge where unpredictable delays are often experienced due to long waiting queues. Secondly, the main road taken is a national highway. This roadway, under normal conditions is highly susceptible to congestion especially during peak hours. Thirdly, this specific national highway was in the process of being widened and thus, under construction at the time of the trials. Due to this construction, the number of lanes were reduced, resulting in the bottlenecking of traffic and causing extended congestion and delays over and above those experienced during peak times.

After the trucking stage, the containers then spent between 1 day 05 hours 45 minutes and 9 days and 20 minutes in the export terminal before being loaded onto the vessel. The vessels sailed from the Port of Cape Town between the dates of 12 May and 10 July 2018. The sea leg of the export journey averaged 14 days 17 hours and 38 minutes as the vessels arrived in the Port of Rotterdam between the dates of 3 June and 25 July 2018. The containers were then offloaded from the vessels in the Port of Rotterdam. Thereafter, the containers were either barged within the Port of Rotterdam before being transported by truck to the final cold store, DC3, or just placed on trucks to await further transport. The containers spent between 07 hours 53 minutes and 3 days 02 hours 30 minutes within the import terminal before exiting the terminal with their respective gate-out date and times. The journey from the port to the final cold store, DC3, is approximately 40 km, which takes the trucks approximately an hour to complete. After arrival, there is often a waiting time at the cold store before the truck is attached to a dock and the container destuffed. This waiting time can vary from minutes to hours as sometimes containers are parked on chassis' on the DC premises for extended periods of time until such a time that the DC is ready to receive their contents.

5.4.2 Apples data analysis

Of the 144 temperature monitoring devices inserted during the apple trials, 111 temperature monitoring devices' data were retrieved. In total, 27 pulp temperature monitoring devices and six ambient temperature monitoring device's data could not be

retrieved, which equates to a 77% retrieval rate. The non-retrievable devices were predominantly due to a full container, namely container seven, not being retrieved. The protocol temperature for apples is -0.55°C (PPECB HP28, n.d.). The definition for a temperature break in the apple cold chain, for the purposes of this research, is if *the temperature exceeds 2°C for 90 minutes or longer or if the temperature falls below -1.5°C for 90 minutes or longer*. If the temperature rises above the specified temperature of 2°C , the senescence of the fruit will accelerate, while if it falls below the -1.5°C specified temperature, the fruit could become susceptible to chilling injury.

As depicted by Table 5.6, 57 container temperature breaks and 371 device temperature breaks were recorded during the apple trials. Both the container and device breaks are summarised per stage in Table 5.6, per container break in Table 5.7 and per device break in Table 5.8. Breaks with temperatures exceeding 2°C are indicated in red, while those with temperatures below -1.5°C are indicated in blue. These temperature breaks are discussed in greater detail, per individual container and stage in section 5.4.2.1 and in Appendix A, Figures 9.1 through 9.5.

Of the 371 device temperature breaks recorded during the apple trials, 301 of those temperature breaks were due to the temperature rising above the specified protocol temperature of 2°C for 90 minutes or longer. The remaining 70 device temperature breaks that were recorded were due to the temperature falling below the specified -1.5°C protocol temperature for 90 minutes or longer. The container breaks results reflected a similar trend where 46 out of the total 57 container breaks recorded were due to the temperature being above protocol temperature for 90 minutes or longer, while eleven were below protocol temperature for 90 minutes or longer.

Table 5:6 Apple temperature trials pulp and ambient temperature break collective results summary per stage

CONTAINER				DEVICE			
STAGE		Pulp GRAND total	Ambient GRAND total		Pulp GRAND total	Ambient GRAND total	
1	Pack house and Cold Store	5	5		82	35	
		0	11		3	47	
2	Trucking to port of export	4	3		19	12	
		0	0		0	0	
3	Port of export	0	0		3	0	
		0	0		2	0	
4	On board vessel at port of export	1	1		3	2	
		0	0		0	0	
5	Sea leg	3	2		12	7	
		0	0		0	14	
6	On board vessel at port of import	3	2		16	8	
		0	0		0	0	
7	Port of import	2	2		14	11	
		0	0		1	2	
8	*Barged	2	2		8	8	
		0	0		0	0	
9	*Port of import post barge	2	0		4	0	
		0	0		0	0	
10	Trucking to cold store	4	3		38	15	
		0	0		1	0	
11	Cold store wait	0	0		4	0	
		0	0		0	0	
12	Destuffed and cold store intake	0	0		0	0	
		0	0		0	0	
		26	31	57	210	161	371
Total hot = >2°C for 90 min+		26	20	46	203	98	301
Total cold <-1.5°C for 90 min+		0	11	11	7	63	70

Table 5:7 Apple temperature trials pulp and ambient collective container breaks summary per container

Apple trials container breaks summary											
CON7		CON8		CON9		CON10		CON11		CON12	
PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT
		6	4	9	7	2	2	5	3	4	4
		0	0	0	11	0	0	0	0	0	0
		6	4	9	18	2	2	5	3	4	4
			10		27		4		8		8

Table 5:8 Apple temperature trials pulp and ambient collective device breaks summary per container

Apple trials device breaks summary											
CON7		CON8		CON9		CON10		CON11		CON12	
PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT
		42	21	47	23	30	12	42	20	42	22
		3	2	0	59	0	0	0	2	4	0
		45	23	47	82	30	12	42	22	46	22
			68		129		42		64		68

The collective pulp and ambient temperature profiles of the apple trials are illustrated in Figures 5.6 and 5.7. The graphs each consist of 7209 viable data points. Figure 5.6 indicates the median pulp and ambient temperature within each stage. Figure 5.7 is a box and whisker plot of the pulp and ambient temperature within each stage. Figure 5.7 gives a clearer indication of the dispersion of data within each stage while also indication the temperatures categorized as outliers.

Apples collective pulp and ambient temperature profiles

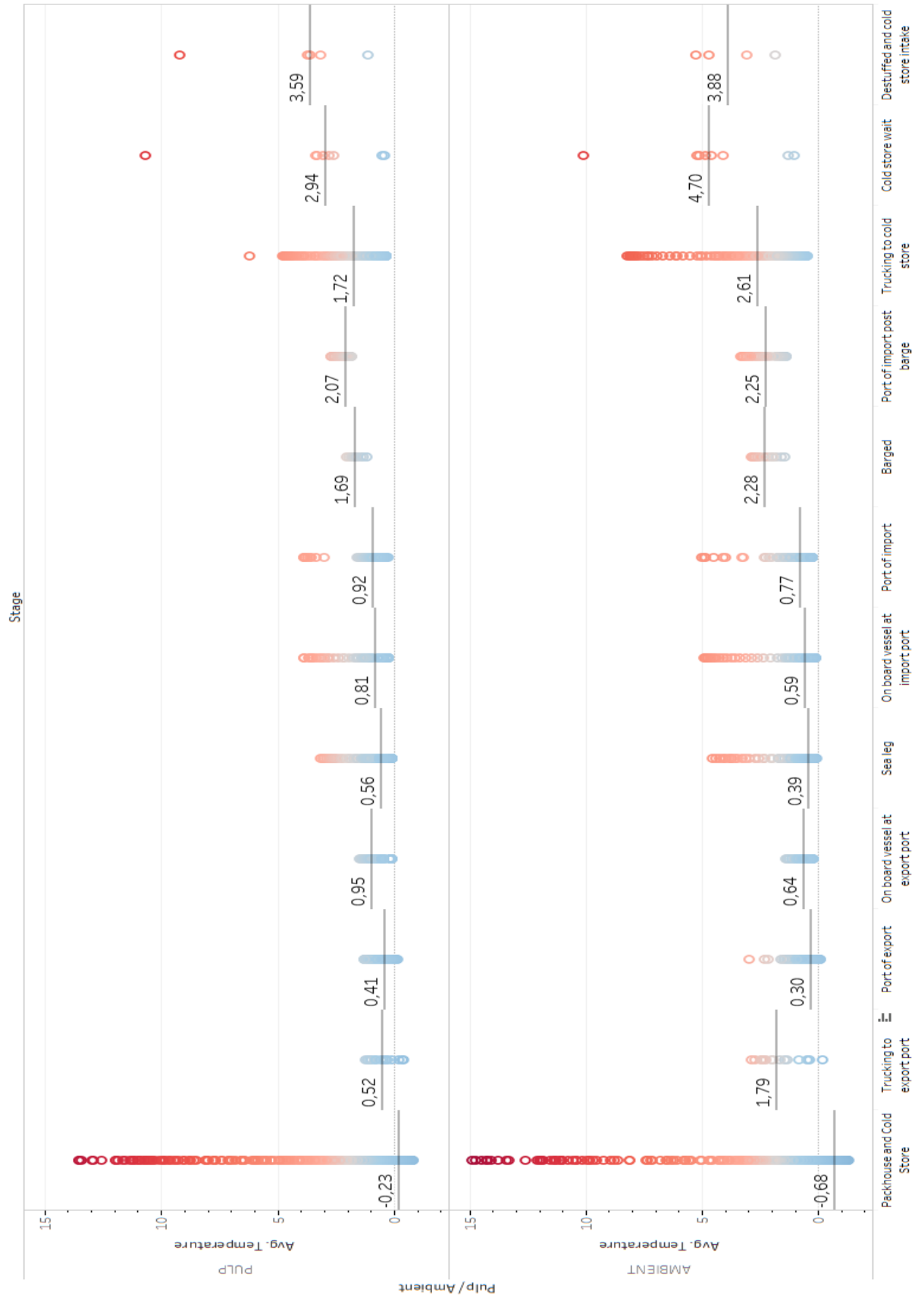


Figure 5.6 Apples trials collective temperature profiles with median temperature per stage

Apples collective pulp and ambient temperature profiles

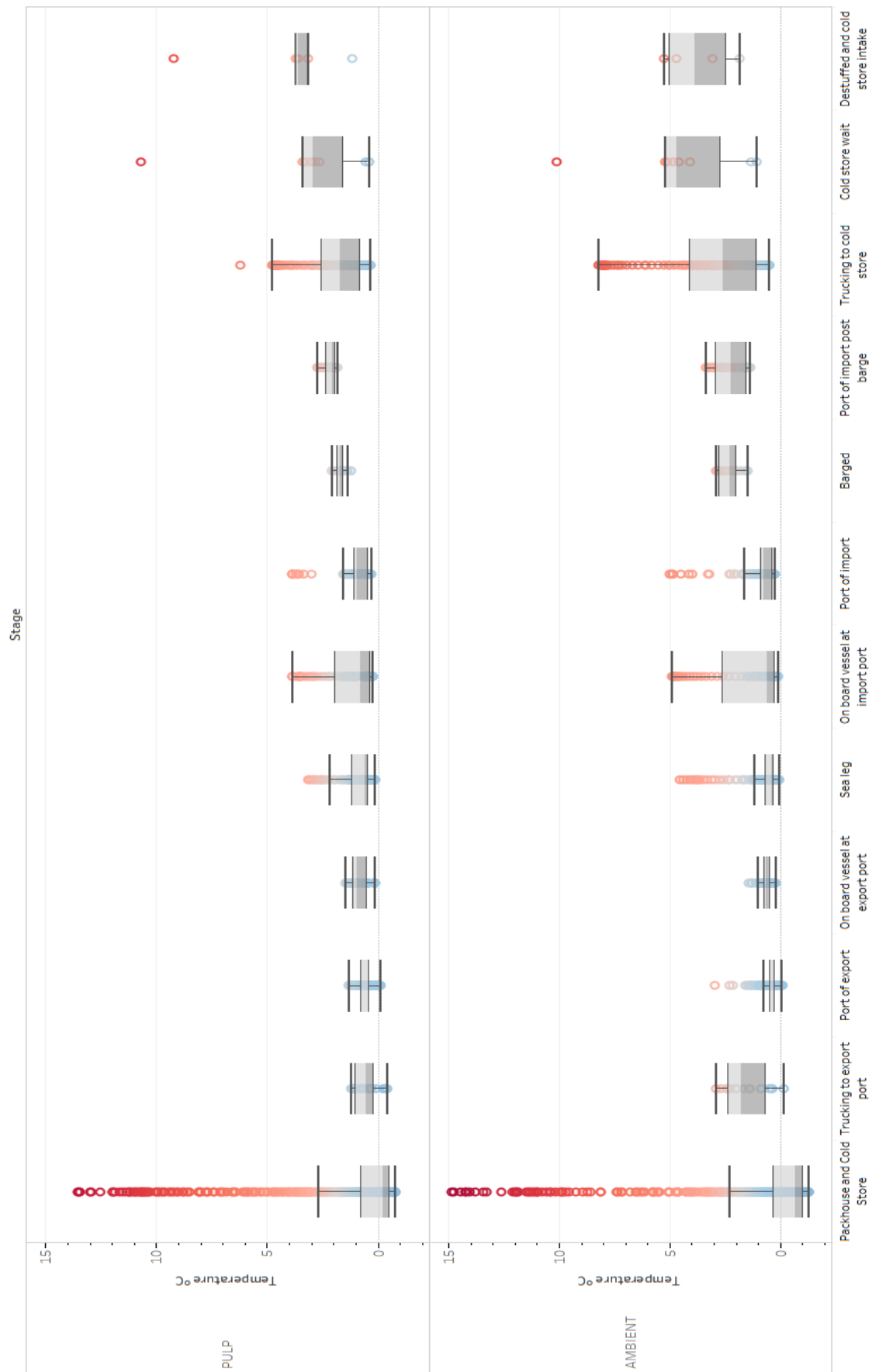


Figure 5.7 Apples trials collective temperature profiles box and whisker plots

5.4.2.1 Section one: SA Leg

Section one consists of the 'pack house and cold store', 'trucking' and 'port of export' stages. The pack-house-and-cold-store stage encompasses all the processes that the apples undergo prior to palletization and container loading. After container loading, the containers are transported via trucks to the port of export where they remain in the reefer stacks until loaded on board the vessel. Collectively looking at all five apple containers for the first section, it was noted that the bottom layers of the pallets had the most rapid decrease in temperature with the top layers having a slightly more gradual decrease. The middle cartons followed an average speed between the rapid bottom pallets and more gradual top pallets. Secondly, the starting temperatures for both the ambient and pulp readings were exceptionally high. The highest pulp temperature in the first stage was recorded in container nine. A temperature of 16.727°C was recorded by logger R5 Pulp Bottom. The highest ambient temperature recorded was at 16.11°C by logger L6 Ambient in container eight. Both these high temperatures were recorded in the first stage of the first section namely, the pack-house-and-cold-store stage. It should be noted that the apples used in these trials had come out of cold storage and had thus, already gone through the initial cooling phase. Therefore, the fact that all containers started out with temperatures well above protocol temperature of -0.55°C and above the allowable variance of 2°C is concerning. Consequently, the initial high temperature starts are considered temperature breaks.

In addition, the likelihood of possible chilling injury occurring during the first section is high as the fruits' temperatures tended to plunge to their lowest throughout the cold chain during this phase in both pulp and ambient measurements. Following the initial decrease in both the pulp and ambient temperatures, resulting from the cooling stage of the pallets, a slight, yet fluctuating rise and fall in temperature was recorded that fell within the prescribed variance allowance. This is most likely attributed to the pallets being removed from the cooling chambers and staged outside for loading into a container, the physical loading itself and the time of year. Furthermore, container nine experienced three distinct spikes during the pack-house-and-cold-store stage, but spent more than double the time in the stage than the other containers. The average time spent in the pack-house-and-cold-store stage was approximately 5 days 04 hours 35 minutes, while container nine spent 13 days 40 minutes. It was later discovered

that the shipment had to be repacked for another client in another country, which caused the delay.

A consistent rise in both ambient and pulp temperatures across all containers was recorded just prior to and at the respective gate-in dates and times. This temperature rise resulted in temperature breaks in both pulp and ambient loggers across all containers. Container ten was the least affected, while container twelve experienced the largest break with logger R1 Pulp Bottom recording 4.001°C. During this temperature break, it was noted that the bottom cartons repeatedly experienced the highest temperatures. Furthermore, during the third stage of section one, namely the port-of-export stage, the bottom cartons continually had the most pronounced temperature spikes and/or breaks. The top cartons also had definite spikes that mimicked those experienced in the bottom layers, but they were often below the 2°C threshold, while the middle cartons had a relatively delayed and gradual rise in temperature. This held true, for all the containers, from the third stage until the end of the export journey. These temperature breaks could be predominantly attributed to the trucking stage as all of the containers experienced temperature fluctuations during transportation.

In addition, it was noted that container eleven experienced numerous temperature fluctuations, although within the protocol range, during the port-of-export stage. It was found that container eleven spent an extended amount of time within this stage of 9 days 20 minutes when compared to the average of 2 days 15 hours 10 minutes. A further peculiar point noted was that of the middle cartons of the back two pallets namely, R9 and L11. These two pallets are the last pallets placed at the door of the container. The middle layer of cartons within those pallets tended to have a slow yet, continuous increase in temperature from the gate-in point until the end of the container's journey. This was the case in the majority of the containers.

The temperature breaks that occurred towards the end of the pack-house-and-cold-store stage as well as at the start of the trucking to port of export phase, often continued into the next phase of the cold chain. This is due to a knock-on effect. Consequently, section one accounted for slightly more than half of all container as well as device temperature breaks for the entire export cold chain.

5.4.2.2 *Section two: Sea Leg*

Section two consists of the 'on board vessel at the port of export' stage, 'sea leg' stage and 'on board vessel and port of import' stage. This section begins and concludes just before and just after the Actual Time of Departure (ATD) and Actual Time of Arrival (ATA) illustrated in Appendices 9.1 through 9.5. Once the vessel is fully loaded and all containers plugged in, the vessel is ready for departure.

Firstly, after the initial increase and then subsequent decrease in temperature recorded around the gate-in times, a smaller, second spike was recorded just prior to ATD. This second, smaller rise in temperature occurs at the overlap of the port-of-export and on-board-vessel-at-export-port stage. Thus, it begins before the container is loaded on board the vessel and continues during the loading process. At this point, once loaded on board the vessel, there is a slight drop in the temperature recorded by both the pulp and ambient loggers. This drop brings the containers closer to the protocol temperature of -0.55°C , where it should ideally remain for the entire journey. Containers nine, eleven and twelve all experienced temperature breaks that originated within the previous section. Containers nine and eleven experienced hot temperature breaks, of which container nine experienced an extended break. Container twelve, however, experienced an extended cold temperature break by logger R1 Pulp Middle that only concluded in the next section, namely section three: NL Port.

During the sea-leg stage, the majority of the containers remained relatively constant, all be it at higher average temperatures than stipulated, but within protocol range. However, containers nine and eleven experienced temperature breaks at approximately the mid-way point of the sea-leg stage. Container nine experienced a gradual increase in the temperatures of pallets L11 and R9 in all three layers, which peaked at approximately the mid-way point of the sea-leg stage before gradually decreasing again. R9 Pulp Bottom recorded the highest temperature of 2.993°C . Despite logger R9 Pulp Bottom recording a temperature break throughout the entire sea leg, it remained at 2.993°C for approximately 45.5 hours before decreasing incrementally. Container eleven experienced a distinct, rapid rise in temperature by all of the probed pallets and by all layers, to varying degrees. Logger L1 Pulp Bottom recorded the highest temperature of 6.323°C during the 25 hour long temperature break. Furthermore, the pallets with the higher recorded temperatures were pallets L1 and R1, which are located against the reefer container's cooling unit. Due to the rapid

nature of the temperature break and its location in the middle of the sea-leg stage and pallets worst affected, it is presumed to be the result of a container malfunction.

During the final stage in section two, on-board-vessel-at-import-port-stage, container eight was the only container to not experience any temperature spikes or breaks, while container twelve did not experienced any new temperature breaks. Containers nine, ten and eleven all experienced new temperature breaks originating within the stage with container ten being the worst affected. Container nine experienced an overall increase in temperature, but only three new temperature breaks were recorded in conjunction with the ongoing three. Container eleven also recorded an overall increase in temperature, but it was incremental and resulted in only two minor temperature breaks in both temperature and duration of approximately 2.4°C for 3.5 hours. In contrast, container ten recorded a container wide temperature break by all ambient and pulp temperature monitoring devices. Temperatures of above 4°C were recorded by eleven of the nineteen pulp and ambient temperature monitoring devices with maximum temperatures of up to 6.11°C recorded within the final stage. Notably, the pallets with the higher temperature break temperatures recorded were located closer to the front of the container at the cooling unit and tended to be on the left side of the container. This temperature break continued into the next sections and concluded at the end of the export journey.

5.4.2.3 Section three: NL Port

Section three consists of the 'port of import' stage as well as the 'barged' and 'port of import post barge' stages, if applicable.

Containers eight and nine were barged while containers ten, eleven and twelve were not. Container eight recorded eight new temperature breaks during the port-of-import stage, but they were relatively shorter in duration averaging approximately 4.5 hours. Furthermore, the maximum temperatures reached were under 3°C with ambient logger L11 Ambient reaching a maximum temperature of 2.89°C and pulp logger L11 Pulp Bottom reaching a maximum temperature of 2.85°C respectively. It was also noted that container eight spent the longest time within the import port terminal at 03 days 02 hours 30 minutes. There was an incremental rise in temperature prior to container eight being barged, whereafter, during the barge journey, twelve out of the twenty three temperature monitoring devices recorded an extended temperature break

that continued until the end of the export journey. Two additional pulp temperature breaks originated at the port-of-import-post-barge stage, recorded by loggers L1 Pulp Top and L1 Pulp Middle and also continued until the end of the export journey. It was noted that the overall temperature as well as the temperature of the temperature breaks continuously increased from the point of being barged until their conclusion at the end of the export cold chain. Thus, the severity of the temperature breaks increased.

Container nine experienced a similar section journey to container eight, but container nine had existing temperature breaks during the port-of-import stage, that originated in the previous stage. Container nine also had a shorter barge trip than container eight at approximately 4 hours in comparison to 7.5 hours. Container nine also experienced an increase in overall temperature during the barge stage, which continued into the start of the port-of-import-post-barge stage, but instead of continuing to increase for the remainder of the journey as with container eight, it had an initial increase before it began to decrease. Container nine experienced eight new temperature breaks during the barged stage. This brought the total number of devices recording a temperature break to thirteen out of twenty three, of which eight were pulp and five were ambient loggers. Temperatures continued to incrementally increase during the first part of the port-of-import-post-barge stage, adding two further devices to the total number of temperature breaks recorded namely, L1 Pulp Top and R1 Pulp Middle. There was a slight decrease in temperature towards the end of the port-of-import-post-barge stage.

Container ten experienced a container wide break that stemmed from the previous stage with logger L1 Pulp Bottom recording the highest temperature of 6.16°C. It continued until the conclusion of the cold chain. It was also noted that the bottom layers experienced warmer temperatures than the remaining layers of sometimes more than 3°C.

Container eleven experienced no new temperature breaks during this stage.

Container twelve experienced ten breaks of which nine were hot and one was cold. There were six pulp temperature breaks, including the cold one, and four ambient temperature breaks. The temperature breaks were relatively short ranging between 1.5 hours to 10 hours at relatively lower temperatures. A maximum temperature of 3.5°C was recorded by logger L11 Ambient and 3.459 by logger L11 Pulp Bottom.

5.4.2.4 *Section four: NL Transport*

The fourth section consists of the 'trucking to cold store', 'cold store wait' and 'destuffed and cold store intake' stages.

After the initial rise in temperatures recorded during the previous section, all of the containers experienced temperature breaks at varying severities with container eleven being the least affected as it did not have any new temperature breaks during section three.

Container eight continued incrementally increasing in temperature throughout the trucking-to-cold-store stage, whereafter it rapidly rose during the cold-store-wait and destuffed-at-cold-store-intake stages. Containers nine, ten and eleven followed similar journeys with an incremental decrease in the overall temperatures towards the end of section three. Hereafter, a rise in the overall temperatures is recorded with maximum temperatures peaking above those recorded in section three. Container eleven experienced the second highest number of new temperature breaks, namely fifteen, that originated within the trucking-to-cold-store stage and continued until the end of the cold chain.

Container twelve experienced a large spike during the trucking-to cold-store stage of the final section. It spent the longest time at the stage of 04 days 11 hours 48 minutes, which is peculiar as all other containers were concluded within a day. The longest time spent by the remaining containers in this stage was 17 hours 35 minutes. During this stage, the container experienced temperatures of just under 9.5°C with pallet L11 recording the highest pulp and ambient temperatures. Logger L11 Pulp Bottom recorded 9.421°C and L11 Ambient recorded 9.11°C. The majority of the breaks lasted for 50 hours or more with the longest break lasting 80 hours. That equates to over three days at an average temperature of 4.56°C and was recorded by R5 Pulp Bottom. The temperatures decreased to within protocol range towards the very end of the trucking phase where it remained. There were only small spikes recorded at the very end of the export journey.

5.4.2.5 *Findings summary*

When looking at the five apple containers collectively, it is clear that there are temperature breaks throughout the export supply chain of apples. Furthermore, it is

also clear that temperature breaks occur in all sections of the export cold chain as well as at different locations and levels within a container.

During the trials, it was noted that the bottom layers of the pallets were observed to have the warmest temperatures out of the three layers and also experienced the most volatile changes in temperature. The bottom layers continually reached the highest temperatures during the temperature breaks and spikes recorded. The top cartons mimicked the bottom cartons, but to a lesser temperature extent. The middle cartons often exhibited a delayed and more gradual response to the fluctuating temperatures, but if heat was gained, it took far longer for the middle cartons to dissipate the heat, if it was dissipated at all. In addition, there were temperature variations between pallets within the same container during the same temperature break. The pallets located at the doors of the container, namely L11 and R9, were predominantly warmer than the remaining pallets. The left side of the container also had a slight tendency of being somewhat warmer than the right, which created a hotspot at pallet L11.

A typical apple container journey began with very high temperatures, which is concerning as the apples were removed from long term cold storage where the temperatures were already at protocol temperature of -0.55°C . Hereafter, the temperatures were reduced relatively quickly, while somewhat erratically. It should be noted that the bottom cartons reached the lowest temperatures during this initial decrease in temperature. After the initial cooling of the pallets, temperature increases were repeatedly identified at two locations. These increases in temperature occurred in and around gate-in as well as ATD. The rise in temperature in and around the gate-in date and time had its origins during the container loading process, which often worsened during the trucking-to-export-port stage and continued after gate-in before its resolution. This rise in temperature is reflected in both the pulp and ambient temperature profiles. It is from this point onwards that both the pulp and ambient average temperatures remained warmer than protocol throughout the remainder of the export cold chain until its conclusion. In addition, it was also from this point onwards where some loggers in the middle layers of the majority of containers gained heat that did not dissipate. These middle cartons remained on an increasing temperature trend until the conclusion of the export journey. The worst effected middle cartons were most often the pallets closest to the door, namely, pallets L11 and R9.

After the initial spike in and around the gate-in time and date, the majority of all the temperatures decreased to below 2°C with the exception of container nine. The second rise in temperature occurred in and around the ATD date and time. This rise in temperature was to a lesser degree than the first spike at gate-in time and date. The second spike originated during the loading process of the container on board the vessel. The overall temperatures did decrease somewhat once the container was loaded on board the vessel and plugged into its power supply. However, the temperatures did not return to the lower temperatures recorded prior to the gate-in increase. Once the vessels had sailed, both pulp and ambient temperatures remained relatively constant with the exception of container eleven. During the sea leg, at approximately the half way mark, container eleven experienced a prominent and rapid temperature rise. It was presumed to be a container malfunction.

A third spike in temperature was just after the ATD of the vessel at the port of import when the containers were off loaded. Containers eight and nine were the only two containers to be barged during section three and also experienced more temperature breaks throughout the section in comparison to the remaining containers. The majority of the temperatures briefly decreased before increasing once more at the overlap of sections three and four. All containers experienced temperature breaks during the final section, some of which originated in the previous stage and only worsened in severity while others occurred during the trucking to cold store phase. All containers then remained at higher temperatures until the conclusion of the export cold chain. Notably, container twelve had a dramatic temperature spike during its extended trucking-to-cold-store stage.

The receiving NL DC, DC3, has an internal traffic light quality control grading system in place during unloading and intake of new stock. The traffic light system grades the fruit's quality and notes any major and minor issues found upon inspection. A green rating equates to a QC Grade A with a description of 'good'. A yellow rating equates to a QC Grade B with a description of 'acceptable with issues'. A red rating equates to a QC Grade of C with a description of 'borderline'. The number of reports per container and their statuses are shown in Figure 5.8. Although the quality reports can be somewhat misleading upon first glance, all containers had minor issues as shown in Figure 5.9. In addition, it should be noted that container nine also had a major issue quality control concern of decay present upon the QC inspection.

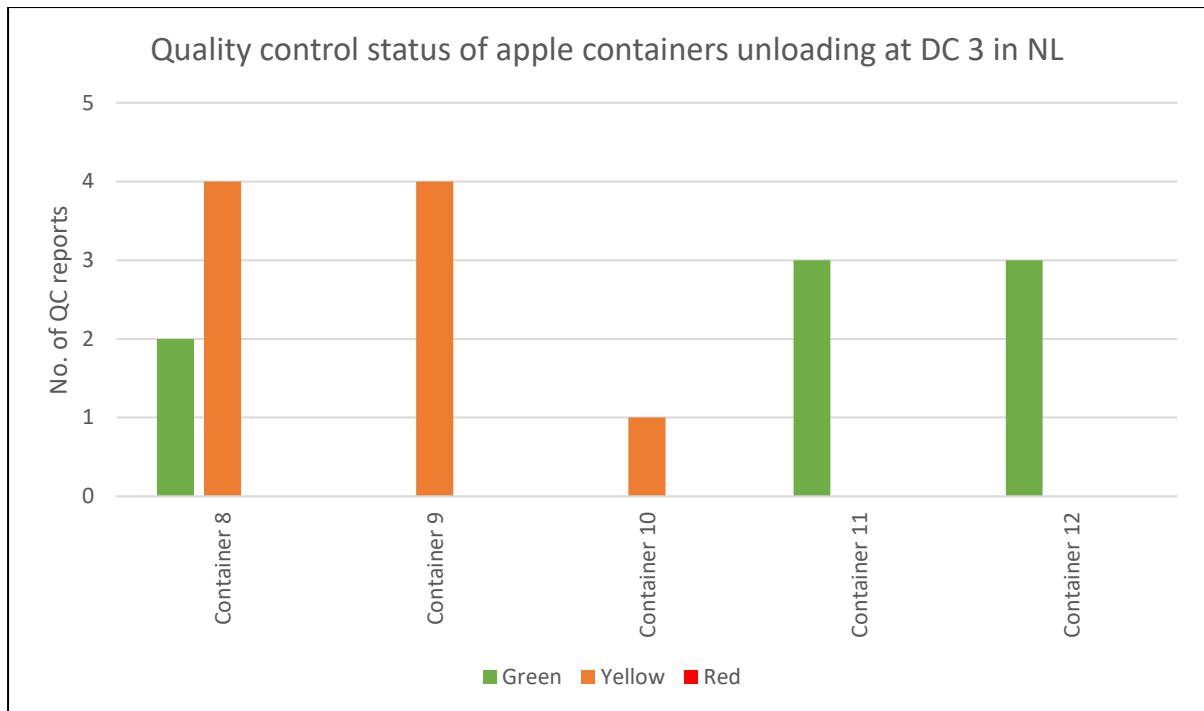


Figure 5.8 Quality control status of apple containers at DC3 in NL

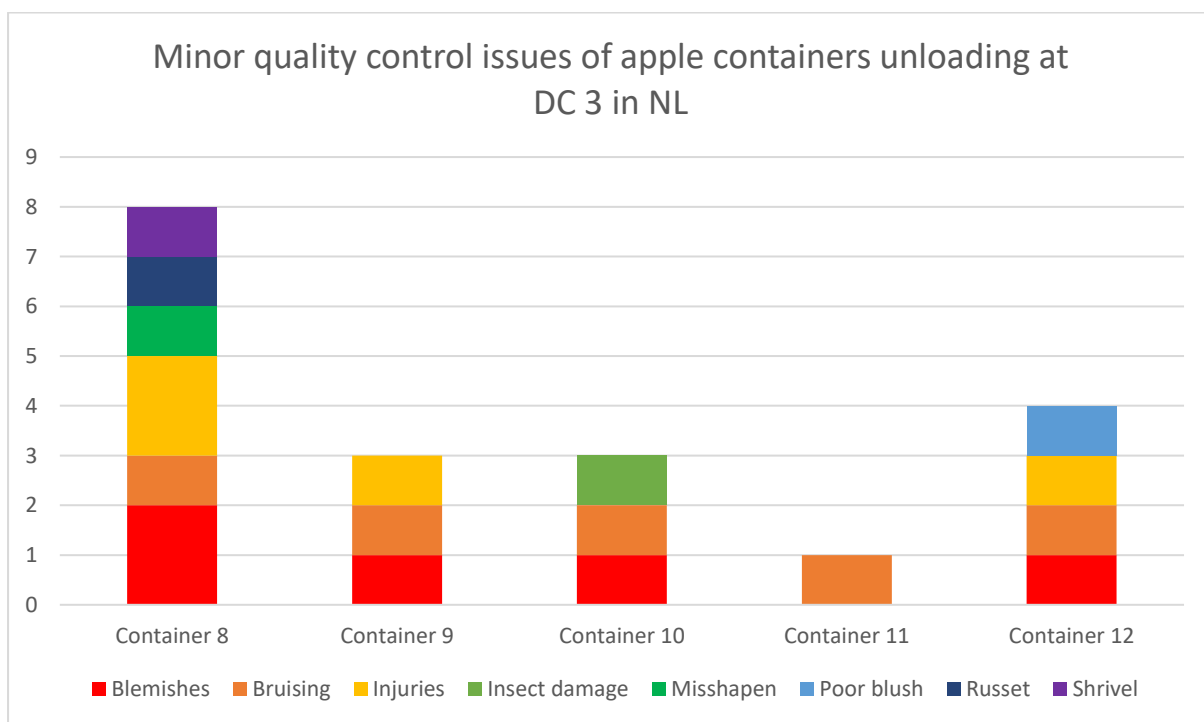


Figure 5.9 Minor QC issues of apple containers at DC3 in NL

5.5 Pears

Pears were the first of the pome fruit trials to be conducted. The trials were conducted from 5 April 2018 until 25 April 2018 and all the pears used in the trials were Abate Fetel pears. The pear temperature trials were conducted at a pack house facility, coded as Pack house A for the purposes of this research. Containers four and five used Shipping line Y while container one, two and six used Shipping line Z. All the pear containers were exported from the Port of Cape Town, in South Africa to the Port of Rotterdam, The Netherlands. Container three was not retrieved in its entirety.

5.5.1 Pears container journeys

The pears used in the trials entered Pack house A between 19 and 21 February 2018 and were placed under controlled atmosphere cold storage. The containers were probed between 5 - 25 April 2018, whereafter, the probed cartons were palletized and moved into a holding room to await a final inspection and labelling before being moved into a cold store prior to being loaded into a refrigerated container. The pallets spent between 4 days, 10 hours and 40 minutes to 13 days 22 hours and 52 minutes in the cold store before being loaded. The containers weight-out dates and times at Pack house A were individually recorded whereafter, the containers were trucked to the Port of Cape Town. The most direct journey is approximately 62km, which would take a truck approximately 1.5 – 2 hours to complete. The average trucking time by the containers was 01 hour 43 minutes from Pack house A to the Port of Cape Town. The containers then spent between 1 day 17 hours 28 minutes and 4 days 03 hours and 41 minutes in the export terminal before being loaded onto the vessel. The vessels sailed from the Port of Cape Town between the dates of 14 April – 12 May 2018. The sea leg of the export journey averaged 15 days 06 hours and 48 minutes as the vessels arrived in the Port of Rotterdam between the dates of 1 May – 26 May 2018. The containers were then offloaded from the vessels in the Port of Rotterdam. Thereafter, the containers were either barged within the Port of Rotterdam before being transported by truck to the final cold store, DC3, or just placed on trucks to await further transport. The containers spent between 9 hours 08 minutes and 3 days 06 hours 02 minutes within the import terminal before exiting the terminal with their respective gate-out dates and times. The journey from the port to the final cold store, DC3, is approximately 40 km, which takes the trucks approximately an hour to complete. After arrival, there is often a waiting time at the cold store before the truck

is attached to a dock and the container destuffed. This waiting time can vary as sometimes containers are parked on chassis on the DC premises for extended periods of time until such a time that the DC is ready to receive their contents.

A more detailed description of the precise happenings within a stage and within a section is shown in Table 5.2. The export journeys of the pear containers are analysed in greater detail in the proceeding section of 5.5 and its subsections.

5.5.2 Pears data analysis

Of the 144 temperature monitoring devices inserted during the pear trials, 111 temperature monitoring devices' data were retrieved. In total, 25 pulp temperature monitoring devices and 8 ambient temperature monitoring device's data could not be retrieved, which equates to a 77% retrieval rate. The non-retrievable devices were predominantly due to a full container, namely container three, not being retrieved. The protocol temperature for pears is -0.55°C (PPECB HP28, n.d.). The definition for a temperature break in the pear cold chain, for the purposes of this research and as per request of Company X, is *if the temperature exceeds 2°C for 90 minutes or longer or if the temperature falls below -1°C for 90 minutes or longer*. If the temperature rises above the specified temperature of 2°C , the senescence of the fruit will accelerate, while if it falls below the -1°C specified temperature, the fruit could become susceptible to chilling injury.

Collectively, there was a grand total of 69 container temperature breaks and 371 device temperature breaks recorded throughout the pear trials as summarized collectively per stage in Table 5.9, per container break in Table 5.10 and per device temperature breaks in Table 5.11. Breaks with temperatures exceeding 2°C are indicated in red, while those with temperatures below -1.5°C are indicated in blue. These temperature breaks are discussed in greater detail, per individual container and stage in section 5.5.2.1 with the accompanying temperature graphs shown in Appendix B, Figures 9.6 through 9.10.

Of the 371 device temperature breaks recorded during the trials, 271 were due to the temperature being above the specified 2°C protocol temperature for 90 minutes or longer. The remaining 100 device temperature breaks recorded were due to the temperature being below the specified -1°C protocol temperature for 90 minutes or longer. The container break results reflected a similar trend where 47 of the 69

temperature breaks recorded were above protocol temperature for 90 minutes or longer and 22 were below protocol for 90 minutes or longer. The stage in the pear trials that experienced the most temperature breaks in pulp and ambient temperature monitors as well as the highest number of both hot and cold temperature breaks was stage one, the pack-house-and-cold-store stage.

Table 5:9 Pear temperature trials pulp and ambient temperature break collective results summary per stage

CONTAINER				DEVICE			
STAGE		Pulp GRAND total	Ambient GRAND total		Pulp GRAND total	Ambient GRAND total	
1	Pack house and Cold Store	6	6		86	36	
		2	20		9	89	
2	Trucking to port of export	4	3		10	5	
		0	0		0	0	
3	Port of export	2	1		8	7	
		0	0		0	0	
4	On board vessel at port of export	0	0		0	2	
		0	0		0	0	
5	Sea leg	3	3		13	17	
		0	0		2	0	
6	On board vessel at port of import	0	0		0	0	
		0	0		0	0	
7	Port of import	1	0		3	0	
		0	0		0	0	
8	*Barged	2	2		8	4	
		0	0		0	0	
9	*Port of import post barge	2	2		11	5	
		0	0		0	0	
10	Trucking to cold store	2	2		10	8	
		0	0		0	0	
11	Cold store wait	1	0		6	0	
		0	0		0	0	
12	Destuffed and cold store intake	4	1		30	2	
		0	0		0	0	
		29	40	69	196	175	371
Total hot = >2°C for 90 min+		27	20	47	185	86	271
Total cold <-1°C for 90 min+		2	20	22	11	89	100

Table 5:10 Pear temperature trials pulp and ambient collective container breaks summary per container

Pear trials container breaks summary											
CON1		CON2		CON3		CON4		CON5		CON6	
PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT
5	6	7	4			4	3	6	3	5	4
0	1	0	0			0	6	1	5	1	8
5	7	7	4			4	9	7	8	6	12
	12		11		0		13		15		18

Table 5:11 Pear temperature trials pulp and ambient collective device breaks summary per container

Pear trials device breaks summary											
CON1		CON2		CON3		CON4		CON5		CON6	
PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT
33	19	38	18			34	18	38	13	42	18
0	8	0	0			0	17	5	18	6	46
33	27	38	18			34	35	43	31	48	64
	60		56		0		69		74		112

The collective pulp and ambient temperature profiles of the pear trials are illustrated in Figures 5.10 and 5.11. The graphs each consist of 7574 viable data points. Figure 5.10 indicates the median pulp and ambient temperature within each stage. Figure 5.11 is a box and whisker plot of the pulp and ambient temperature within each stage. Figure 5.11 gives a clearer indication of the dispersion of data within each stage while also indication the temperatures categorized as outliers.

As explained earlier in section 5.3.2, the pear trials were the worst effected by devices that malfunctioned during the later stages of the trials. These ambient outliers can be seen in the bottom half of Figures 5.10 and 5.11 as the deep orange to red circles within the red box from the sea-leg stage through to the end at the destuffing-and-cold-store-intake stage. The median ambient temperatures of the barged & port-of-import-post-barge stage without the device malfunctions are 1.65°C and 3.33°C respectively and not 14.8°C and 15.5°C as indicated. After the initial analysis, further investigation was prompted into the section breaks.

Pears collective pulp and ambient temperature profiles

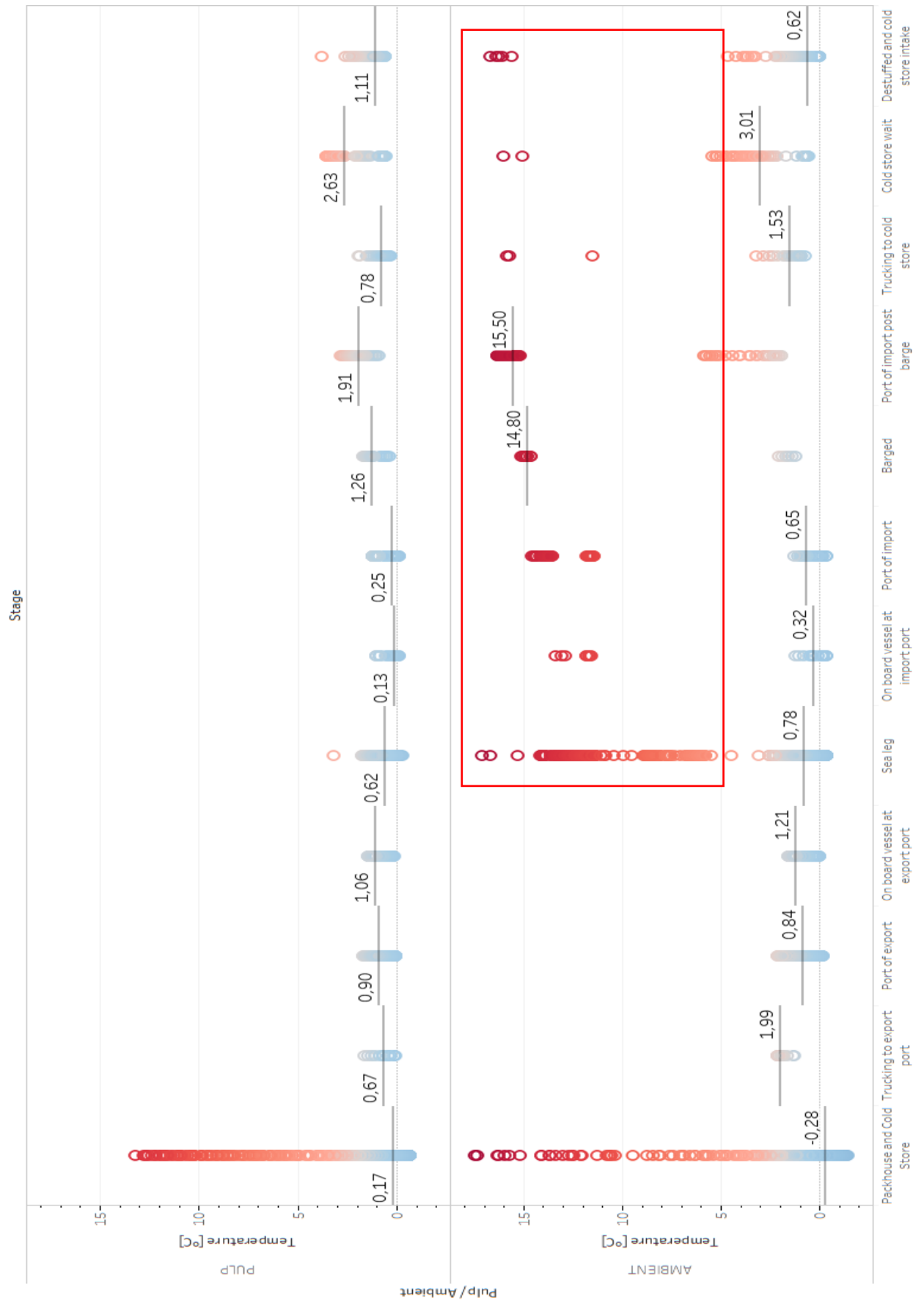


Figure 5.10 Pears trials collective temperature profiles with median temperature per stage

Pears collective pulp and ambient temperature profiles

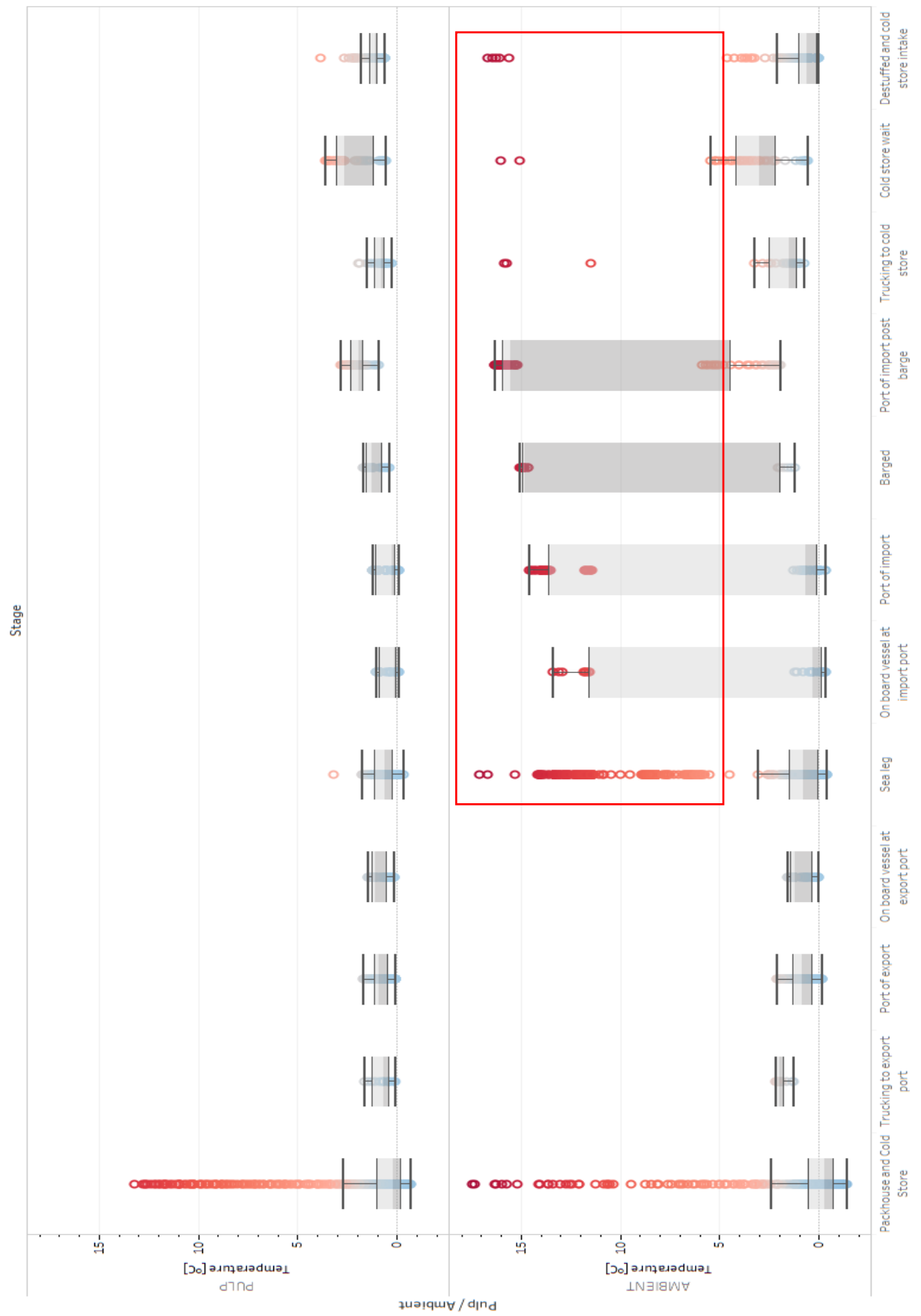


Figure 5.11 Pears trials collective temperature profiles box and whisker plots

5.5.2.1 *Section one: SA Leg*

Section one consists of the 'pack house and cold store', 'trucking' and 'port of export' stages. The pack-house-and-cold-store stage encompasses all the processes that the pears undergo prior to palletization and container loading. Once loaded, the pear containers are trucked to the port of export and ultimately remain in the stacks until they are loaded onto the vessel. By looking collectively at all five pear containers for the first section, it was noted that the bottom layers of the pallets had the most rapid decrease in temperature with the top layers having a slightly more gradual decrease. The middle cartons followed an average speed between the rapid bottom pallets and more gradual top pallets. Secondly, the starting temperatures for both the ambient and pulp readings were exceptionally high. The highest pulp temperature in the first stage was recorded in container four. A temperature of 18.716°C was recorded by logger R1 Pulp Bottom. This logger continued to record the highest temperatures throughout the export chain. The highest ambient temperature, was recorded at 25.56°C, in container two, by logger R9 Ambient. It should be noted that the pears used in these trials had come out of long-term cold storage and had thus, already gone through the initial cooling phase and had been stored at protocol temperature. Therefore, the fact that all containers started out with temperatures well above protocol temperature of -0.55°C and above the allowable variance of 2°C is concerning. Consequently, the initial high temperature starts are considered temperature breaks.

In addition, there was also a high likelihood of possible chilling injury taking place during the first stage as the temperatures tended to plunge to their lowest throughout the cold chain during this phase in both pulp and ambient measurements. After the initial decrease in temperature, resulting from the cooling stage of the pallets, there was always a rise in temperature that fell within the prescribed variance allowance. This is most likely attributed to the pallets being removed from the cooling chambers and staged for loading into a container as well as the physical loading itself.

Another rise in temperature was repeatedly recorded prior to the gate-in date and time during which the majority of the bottom cartons experienced a temperature break. It was noted that for this temperature break, the bottom cartons always had the most pronounced temperature spikes and/or breaks. The top cartons also had definite spikes, but they were often below the 2°C threshold, while the middle cartons had a relatively smooth, slight rise. These temperature breaks could be predominantly

attributed to the trucking stage as the majority of the containers experienced an overall increase in temperature resulting in fluctuations during transportation. Additional reasons for the later temperature spikes and breaks can also be attributed to the port-of-export stage itself, as a result of congestion around as well as within the port and natural delays such as rough sea and wind conditions.

The temperature breaks that occurred towards the end of the pack-house-and-cold-store stage and even at the start of the trucking to port-of-export stage, often continued into the next stage of the cold chain as a knock-on effect. As a result, section one accounted for approximately two thirds of all container as well as device temperature breaks for the entire export cold chain.

5.5.2.2 Section two: Sea Leg

Section two consists of the 'on board vessel at the port of export' stage, 'sea leg' stage and 'on board vessel and port of import' stage. This section begins and concludes just before and just after the Actual Time of Departure (ATD) and Actual Time of Arrival (ATA) as illustrated in in Appendices 9.6 through 9.10. Once the vessel is fully loaded and all containers plugged in, the vessel is ready for departure. At this point, there is a slight drop in the temperature. This drop brings the containers back closer towards the protocol temperature of -0.55°C , where it should ideally remain for the entire journey.

As noted previously, two containers experienced temperature breaks that arose from a previous stage, namely containers one and two. These breaks could possibly stem from the containers being left unplugged, on a hot surface, dockside prior to loading for a significant period of time as the bottom cartons registered the temperature breaks. In addition, the anomalies discussed in section 5.3.2, occurred during section two. The affected temperature monitoring devices were ambient loggers L11, R1, R5 and R9 in container one and ambient loggers L6 and L11 in container two. However, container two experienced the first ambient device, L11 Ambient, dramatically increase in temperature and approximately a week later, the second device, L6 Ambient, mimicked the first. There was not a dramatic rise in the pulp temperature monitors of either container when the ambient temperature monitoring devices malfunctioned. In conjunction to this, container two had an additional temporary

malfunction of device L1 Pulp Middle that gave a single, incredibly high reading of 63.935°C.

A further anomaly in container five was noted as logger R9 Pulp Top had approximately four very low temperature readings with the lowest reaching -12.253°C towards the end of the sea-leg stage. This could result in severe chilling injury for the fruit. However, there was no change in the rest of the container. Reefer containers capable of carrying frozen goods are capable of reaching such low temperatures. This should, therefore, be noted for further investigation.

Container six presented with a clear rise and subsequent break in the temperatures recorded in both the pulp and ambient temperature monitoring devices approximately just after half way through the sea-leg stage. It's assumed that there was a fault with the container that was subsequently repaired by crew as the temperatures later returned within protocol range. The maximum pulp temperature reached was 3.175°C and the longest temperature break lasted for 15.5 hours. The maximum ambient temperature reached was slightly lower at 3.06°C with a duration of 9.5 hours. This illustrates the principle of fruit taking longer to give off heat at a pulp level and return to protocol temperature than the air surrounding it.

Overall, the sea-leg stage accounted for all of the container breaks and for 32 out of 34 device breaks recorded in this section. The vast majority of the temperature breaks recorded can almost certainly be explained and interpreted as device malfunctions. The sea leg was fairly stable and constant across most of the containers. Some fluctuations in temperatures were recorded. However, in containers four and six the sea leg was particularly uneven and incrementally turbulent.

5.5.2.3 Section three: NL Port

Section three consists of the 'port of import' stage as well as the 'barged' and 'port of import post barge' stages, if applicable. Containers two and six were barged, while the remaining three containers were not. Container one, four and five had no temperature breaks during their port-of-import stage, bar container one's existing ambient breaks as discussed previously in section two, 5.5.2.2. There was, however, a slight rise in temperature, especially towards the end of the port-of-import stage. This rise was still within the specified allowable variance. This concludes section three for containers one, four and five.

Container two experienced two new pulp temperature breaks, namely L6 Pulp Bottom and L11 Pulp Bottom in conjunction with the two ambient temperature breaks as previously highlighted in section two, 5.5.2.2. These two pulp breaks continued from the port-of-import stage into the barged stage with increasing temperatures. Four additional temperature breaks were incurred during the 'barged' phase with the bottom pulp loggers of pallets L1, R1 and R9 as well as R9 Ambient. These eight temperature breaks continued into the next stage, namely, port-of-import-post-barge. During the final stage of section three, four additional pulp temperature breaks were recorded. Twelve out of the eighteen temperature monitoring devices inserted recorded temperature breaks with an average temperature of just under 4°C. Container six presented with a similar journey.

Container six did not experience temperature breaks within the port-of-import stage, but temperatures did increase slightly towards the end of the stage. During the barged stage, seven temperature breaks were recorded that rose slightly over the 2°C threshold. These breaks continued into the next stage where their temperatures rose more rapidly. In total, fifteen temperature breaks were recorded in the port-of-import-post-barge stage. Despite container six having more temperature breaks reaching higher maximum temperatures than container two, the remaining pallets in container six remained at cooler temperatures than those found in container two. Thus, container six essentially had hot spots, while container two had a hotter overall container load.

Looking at section three in its entirety, it is evident that there is always a slight rise in the temperature just after the container is offloaded from the vessel. The containers that were not barged, but rather immediately trucked, seemed to stabilize and even cool their temperatures slightly. This is presumably due to the fact that the container was plugged into the truck as a power supply for the genset to switch on again during its transportation to the cold store. The containers that were barged tended to become incrementally warmer as time passed due to the fact that the containers are not plugged in during the barge trips. This resulted in the temperature breaks continuing into the next stage and even some continuing to the conclusion of the cold chain.

5.5.2.4 Section four: NL Transport

The fourth section consists of the 'trucking to cold store', 'cold store wait' and 'destuffed and cold store intake' stages. After the initial spike in temperature towards the end of

stage three, there was another spike that followed soon afterwards. The second spike was marginally cooler than the first spike, but still recorded temperature breaks. The two barged containers had temperature breaks that extended from the previous section until the end of the recorded cold chain. The containers that were trucked, however, had temperature breaks register towards the end of the trucking-to-cold-store stage and continue into the cold-store-wait stage. A possible reason for this is truck drivers may be encouraged to switch off their trucks instead of running idle to conserve fuel. Alternatively, containers can also be parked outside the cold store facility on chassis without the physical tractor truck and thus, without a power source. Container six was the only container to register new temperature breaks during the cold-store-wait stage. It had the longest wait of more than double any of the other containers at 27.5 hours before being attached to the dock and destuffed. It should be noted that within container six, logger L6 Pulp Bottom possibly malfunctioned as readings of above 24°C were recorded. In addition, it should also be noted that the ambient loggers in 4 out of the 5 containers reached their recording capacity towards the end of the export journey and stopped recording.

Temperatures inevitably did rise slightly when container doors were opened and unloading began, which resulted in additional temperature breaks being registered on the remaining devices during the final stage. As the container is being destuffed, the pallets get staged in front of the loading and/or unloading area for inspections to take place before the fruit enters DC3. This area is refrigerated with strict temperature controls. This can be seen in the pallet's temperature profiles as the temperatures slowly decline and stabilize after initial unloading. It was at this point that the temperature monitoring devices were retrieved from the pear cartons and taken away for data retrieval.

5.5.2.5 Findings summary

Temperature breaks do occur across the export cold chain of pears from South Africa to The Netherlands as all five containers experienced multiple temperature breaks in multiple stages. Throughout all five containers, it was found that the bottom cartons tended towards having the most radical fluctuations when temperatures changed. The bottom layers of the pallets would be the first to rise when temperature breaks were experienced and would also rise to the highest temperatures recorded during those temperature breaks. The second warmest layer were the top cartons as they almost

exactly mimicked the bottom cartons, but at lower temperatures. The middle cartons did not tend to have as defined rapid spikes and fluctuations, but rather had a more gradual temperature increase. Moreover, the middle layer also had the longest after effect of a temperature break as once the heat was gained, it took much longer to dissipate in comparison to the other two layers.

A typical pear container journey started with high temperatures, which is a cause for concern due to the fact that the pears had previously been in cold storage. This is illustrated in section one: SA Leg as it accounted for almost two thirds of all the temperature breaks recorded. Despite the concerning start, the pulp and ambient temperatures were brought back within protocol range from the initial highs relatively quickly. There was always a distinct rise in temperature at two places after the initial cooling of the pallets. The initial rise occurred in and around gate-in date and time, while the second occurred in and around ATD. The rise around gate-in had its origins during the container loading process as there was a gradual increase in overall temperatures. This often worsened during the trucking-to-export-port stage, where it often culminated in a temperature break. This temperature break continued into the next section, the port-of-export stage, after the gate-in point, before it finally concluded. This rise in temperature is reflected in both the pulp and ambient temperatures recorded. It is from this point onwards that both the pulp and ambient average temperatures remained warmer throughout the duration of the export cold chain until its completion.

The second rise in temperature occurred in and around the ATD date and time. This rise in temperature was to a lesser degree than the previous spike at gate-in. This temperature spike had its origins during the loading process of the container on board the vessel. Temperatures did increase in all containers, but only resulted in temperature breaks in containers one and two. Those temperature breaks also did not exceed 3°C. Once the containers were loaded and plugged into the vessel's power supply, there was a slight decrease in overall temperatures. Once the vessels had sailed, both pulp and ambient temperatures fluctuated. Containers four and six were particularly erratic in the fluctuations, while containers one, two and five remained somewhat stable. All of the containers did, however, have large disparities between pallet layers as seen in the wide spread of the time series lines in Appendices chapter nine section two, Figures 9.6 through 9.9. Notably, during the sea leg, at approximately

the half way mark, container six experienced a temperature break. The overall temperature of the container had begun to rise during the early morning hours of 15 May 2018 and continued doing so incrementally until its peak, where it caused a temperature break at around midday 20 May 2018. Both the ambient and pulp temperature monitoring devices reflected this. It was presumed to be a container malfunction.

A third spike in temperature occurred just after the ATD of the vessel at the port of import when the containers were off loaded. Container two and six were the only two containers that were barged within section three: NL Port. Both containers experienced multiple temperature breaks during the barged stage. Container two had a few that originated in the previous stage and worsened in conjunction to the new temperature breaks. Both containers two and six had the temperature breaks continue into the next stages until the conclusion of the cold chain export journey. Containers one, four and five experienced slight temperature fluctuations, but remained within protocol range with no temperature breaks recorded in section three: NL Port. Container one was the least affected as no new temperature breaks were recorded until the container was destuffed where temperatures rose somewhat. Containers four and five had similar journeys in section four: NL Transport. Both containers experienced temperature breaks originating during the trucking-to-cold-store-stage and continuing into the cold-store-wait stage. Some temperature breaks then continued into the destuffed-and-cold-store-intake stage. Both containers' temperatures then decreased to protocol range before experiencing a second temperature break in the destuffed-and-cold-store-intake stage. It should be noted that container four and five spent an extended amount of time in the final stage.

The receiving NL DC, DC3, has an internal traffic light quality control grading system in place during unloading and intake of new stock. The traffic light system grades the fruit's quality and notes any major and minor issues found upon inspection. A green rating equates to a QC Grade A with a description of 'good'. A yellow rating equates to a QC Grade B with a description of 'acceptable with issues'. A red rating equates to a QC Grade of C with a description of 'borderline'. The number of reports per container and their statuses are shown in Figure 5.12. Although the quality reports can be somewhat misleading upon first glance, all containers had minor issues as shown in

Figure 5.13. In addition, it should be noted that containers five and six also had a major issue quality control concern of mould growth present upon the QC inspection.

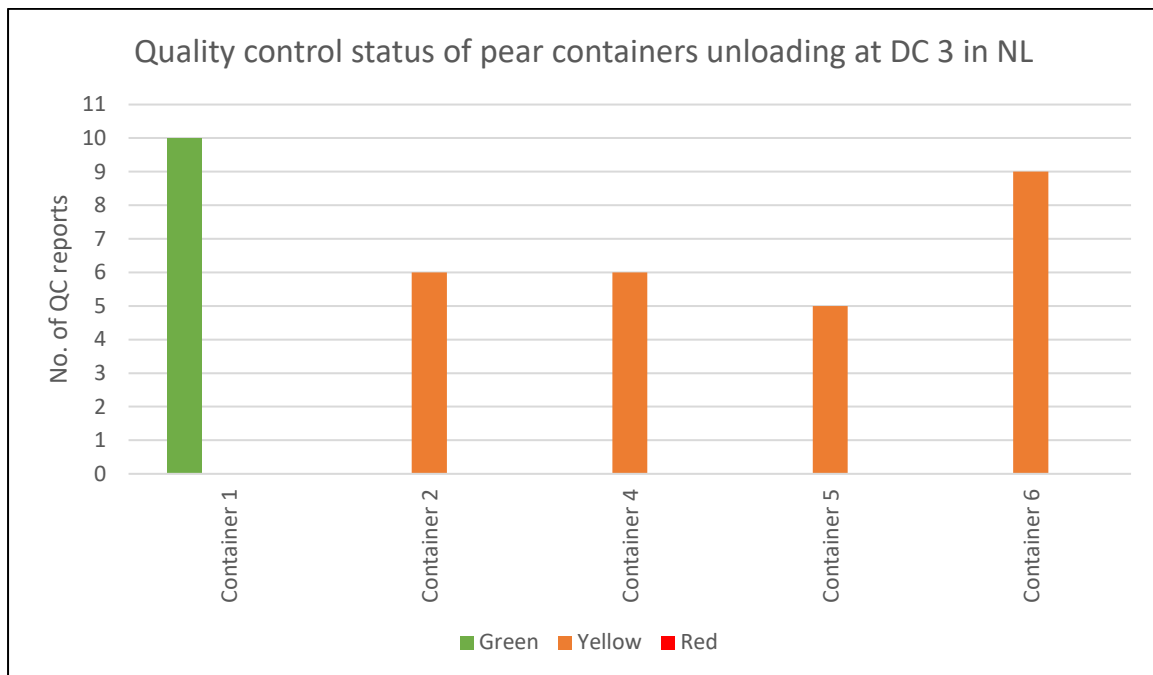


Figure 5.12 Quality control status of pear containers at DC3 in NL

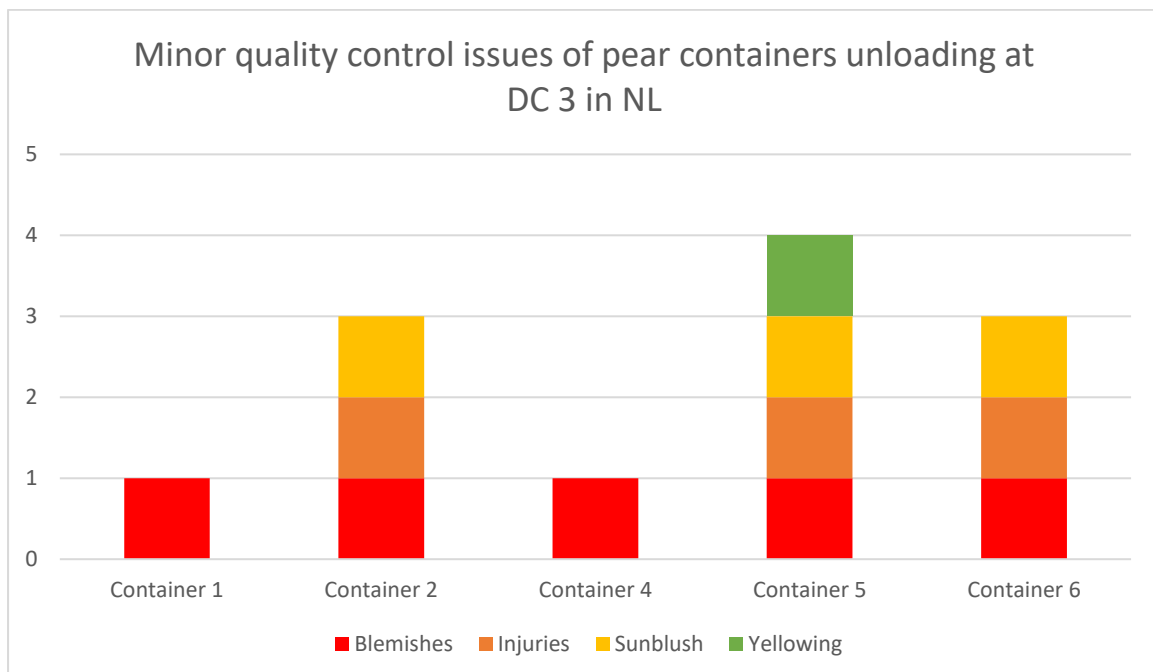


Figure 5.13 Minor QC issues of pear containers at DC3 in NL

5.6 Table grapes

Table grapes were the first of all the temperature trials to be conducted due to their limited season and production volume concerns as a result of a severe draught in the Western Cape region at the time. The trials commenced on 12 February 2018 and concluded on 14 March 2018. A total of twelve containers were probed using three different farms and three different red seedless grape varieties. These varieties are namely, Sweet Celebration®, Crimson Seedless® and Sugranineteen® also more commonly known as Scarlotta. The major difference between the pome and table grape temperature trials was the ratio of pulp to ambient temperature probes. As individual grape berries were too small to house a pulp iButton® temperature monitoring device, a Temptale® 4 steel probe was used to skewer several berries for a more accurate pulp temperature reading. Figures 5.14 and 5.15 depict examples of the pulp and ambient probes. This was only done for the middle carton of two pallets per container, due to device limitations, while the remaining probes were all ambient temperature probes. Therefore, of the 216 temperature monitoring devices inserted, 24 were pulp temperature monitoring devices and 192 were ambient temperature monitoring devices.



Figure 5.14 Temptale® 4 Pulp probe

Source: Authors own



Figure 5.15 Ambient probe

Source: Authors own

The table grape temperature trials were conducted at pack houses on three farms located in the Hex River Valley and De Doorns region of the Western Cape, South Africa, coded as Farm A, B and C for the purposes of this research. From here, the table grapes proceeded to be transported to either of two cold stores, coded as Cold store A and Cold store B for the purposes of this research. Containers one through eight used Shipping line Y and containers nine through twelve used Shipping line Z. It should be noted that container eight was exported using a shipping line W container. All the containers were exported from South Africa through the Port of Cape Town. Container seven was imported into Europe through the Port of Rotterdam, The Netherlands, while all the remaining containers were imported into the United Kingdom through the Port of London Gateway.

5.6.1 Table grapes container journeys

The table grapes used in the trials were probed and palletized on the same day as they entered the respective pack houses. These dates were between 12 February and 14 March 2018. The table grapes were harvested by hand, placed into yellow, cushioned crates and collected by a tractor in the vineyards. The collected crates were then offloaded from the tractor at the centralized pack house and stacked under roof prior to being placed onto the sorting conveyer belt. The pack houses are cooled to approximately 22°C to assist in dissipating some of the fruit's field heat. Once the table grapes had been sorted, weighed and packaged by hand at the tables, the cartons were probed before being stacked and palletized. The probed pallets were then moved to a holding area to await a final inspection and labelling before being trucked to the respective cold stores. The pallets spent between approximately 04 hours 21 minutes and 09 hours 22 minutes in the pack houses before being trucked to the cold stores. Containers four, six and eight were trucked to Cold store B in a refrigerated truck, as it is approximately a three hour journey. The remaining containers were trucked to Cold store A with a non-refrigerated truck, as the journey takes less than 5 minutes. Upon arrival at the cold stores, the pallets are offloaded and placed directly into forced air cooling (FAC) tunnels to rapidly lower the table grapes temperature to -0.5°C, which can take from 12 to 72 hours. Once completed, the cooled pallets are removed from the FAC tunnels and placed into large, cooled holding rooms to await final loading instructions. When the loading instructions are received, the pallets are removed from the holding rooms and placed into a staging area. This area is where the pallets are

staged for each container prior to loading. Hereafter, the staged pallets are moved to the adjacent loading area before being loaded into the reefer container. The pallets spent between approximately 2 days 09 hours 19 minutes and 7 days 02 hours 19 minutes in the cold store. The containers weight-out dates and times at cold stores A and B were individually recorded whereafter, the containers were trucked to the Port of Cape Town. The most direct route from Cold store A to the Port of Cape Town is approximately 137 km, which would take a truck approximately 2 to 2.5 hours to complete. The average trucking time recorded from Cold store A was 4 hours 03 minutes. The most direct route from Cold store B to the Port of Cape Town is approximately 23 km, which would take a truck approximately 1 to 1.5 hours to complete. The average trucking time recorded from Cold store B was 2 hours 08 minutes. In terms of the route from Cold store A to the Port of Cape Town, the delay is due to three main reasons. Firstly, this journey involves the mandatory use of a weigh bridge where unpredictable delays are often experienced due to long waiting queues. Secondly, the main road used for this route is a national highway. This roadway, under normal conditions is highly inclined to congestion especially during peak hours. Thirdly, this specific national highway was in the process of being widened and thus, under construction at the time of the trials. Due to this construction, the number of lanes were reduced, resulting in the bottlenecking of traffic and causing extended congestion and delays over and above those experienced during peak times. Regarding the route from Cold store B, it was only affected by the second and third reasons as it does not bypass the weigh bridge.

The containers then spent between 1 day 16 hours 41 minutes and 7 days 12 hours and 18 minutes in the export terminal before being loaded onto the vessel. The vessels sailed from the Port of Cape Town between the dates of 22 February and 20 March 2018. The sea leg of the export journey averaged 15 days 12 hour and 04 minutes as the vessels arrived in the Port of London Gateway between the dates of 10 March and 4 April 2018. The containers were then offloaded from the vessels in the Port of London Gateway. Thereafter, the containers were trucked to the final cold stores, DC1 and DC2. The containers spent between 12 hours 23 minutes and 2 days 16 hours 56 minutes within the import terminal before exiting the terminal with their respective gate-out date and times. The journey from the port to the final cold store, DC3, is approximately 40 km, which takes the trucks approximately an hour to complete. After

arrival, there is often a short waiting time at the cold store of between 12 and 40 minutes before the truck is attached to a dock and the container is destuffed.

5.6.2 Table grapes data analysis

Of the 216 temperature monitoring devices inserted in the table grape temperature trials, 192 temperature monitoring devices' data was received. Altogether, four pulp and 20 ambient temperature monitoring devices' data could not be retrieved. This equates to approximately an 89% retrieval rate. The bulk of the non-retrievable devices were predominantly due to a full container, namely container seven, not being retrieved. The protocol temperature for table grapes is -0.55°C (PPECB HP28, n.d.). The definition for a temperature break in the table grape export cold chain, for the purposes of this research, is if the temperature exceeds 2°C for 90 minutes or longer or if the temperature falls below -1.5°C for 90 minutes or longer. If the temperature rises above the specified temperature of 2°C , the senescence of the individual table grapes will accelerate, while if it falls below the -1.5°C specified temperature, the table grapes could become susceptible to chilling injury.

In total, there were 53 container temperature breaks and 440 device temperature breaks recorded throughout all the table grape trials. These results are summarized collectively, per stage, in Table 5.12, container breaks per container in Table 5.13 and device breaks per container in Table 5.14. Breaks with temperatures exceeding 2°C are indicated in red, while those with temperatures below -1.5°C are indicated in blue. These temperature breaks are discussed in greater detail, per individual container and stage in section 5.6.2.1 and Appendix C, Figures 9.11 through 9.21.

Of the 440 device temperature breaks recorded during the trials, 432 were due to the temperature being above the specified 2°C protocol temperature for 90 minutes or longer. The remaining eight device temperature breaks recorded were due to the temperature being below the specified -1.5°C protocol temperature for 90 minutes or longer. The container break results showed a similar trend where 50 of the 53 breaks recorded were above protocol temperature for 90 minutes or longer and three were below -1.5 for 90 minutes or longer. The stage in the table grape trials that experienced the most temperature breaks in pulp and ambient temperature monitors was stage one, the pack-house stage.

Table 5:12 Table grape temperature trials pulp and ambient temperature break collective results summary per stage

CONTAINER				DEVICE			
STAGE		Pulp GRAND total	Ambient GRAND total		Pulp GRAND total	Ambient GRAND total	
1	Pack house	10	11		20	209	
		0	0		0	0	
2	Cold store	1	9		9	112	
		0	3		0	8	
3	Loading into container	0	1		0	10	
		0	0		0	0	
4	Trucking to port of export	0	6		0	18	
		0	0		0	0	
5	Port of export	1	7		3	35	
		0	0		0	0	
6	On board vessel at port of export	0	0		0	1	
		0	0		0	0	
7	Sea leg	1	2		1	12	
		0	0		0	0	
8	On board vessel at port of import	0	1		0	1	
		0	0		0	0	
9	Port of import	0	0		0	1	
		0	0		0	0	
10	Trucking to cold store	0	0		0	0	
		0	0		0	0	
11	Cold store wait	0	0		0	0	
		0	0		0	0	
12	Destuffed and cold store intake	0	0		0	0	
		0	0		0	0	
		13	40	53	33	407	440
Total hot = >2°C for 90 min+		13	37	50	33	399	432
Total cold <-1.5°C for 90 min+		0	3	3	0	8	8

Table 5:13 Table grape temperature trials pulp and ambient collective container breaks summary per container

Table grape trials container break summary											
CON1		CON2		CON3		CON4		CON5		CON6	
PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT
1	3		4	2	2	1	3	2	4	2	8
0	0		2	0	0	0	0	0	0	0	0
1	3	0	6	2	2	1	3	2	4	2	8
	4		6		4		4		6		10
CON7		CON8		CON9		CON10		CON11		CON12	
PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT
		1	4	1	1	1	5	1	2	1	1
		0	0	0	0	0	0	0	1	0	0
0	0	1	4	1	1	1	5	1	3	1	1
	0		5		2		6		4		2

Table 5:14 Table grape temperature trials pulp and ambient collective device breaks summary per container

Table grape trials device break summary											
CON1		CON2		CON3		CON4		CON5		CON6	
PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT
9	38	0	29	4	39	2	81	5	38	3	64
0	0	0	6	0	0	0	0	0	0	0	0
9	38	0	35	4	39	2	81	5	38	3	64
	47		35		43		83		43		67
CON7		CON8		CON9		CON10		CON11		CON12	
PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT	PULP	AMBIENT
		2	22	2	17	2	38	2	17	2	16
		0	0	0	0	0	0	0	2	0	0
0	0	2	22	2	17	2	38	2	19	2	16
	0		24		19		40		21		18

The collective pulp and ambient temperature profiles of the table grape trials are illustrated in Figures 5.16 and 5.17. The graphs each consist of 12 317 viable data points. Figure 5.16 indicates the median pulp and ambient temperature within each stage. Figure 5.17 is a box and whisker plot of the pulp and ambient temperature within each stage. Figure 5.17 gives a clearer indication of the dispersion of data within each stage while also indicating the temperatures categorized as outliers.

Table grapes collective pulp and ambient temperature profiles

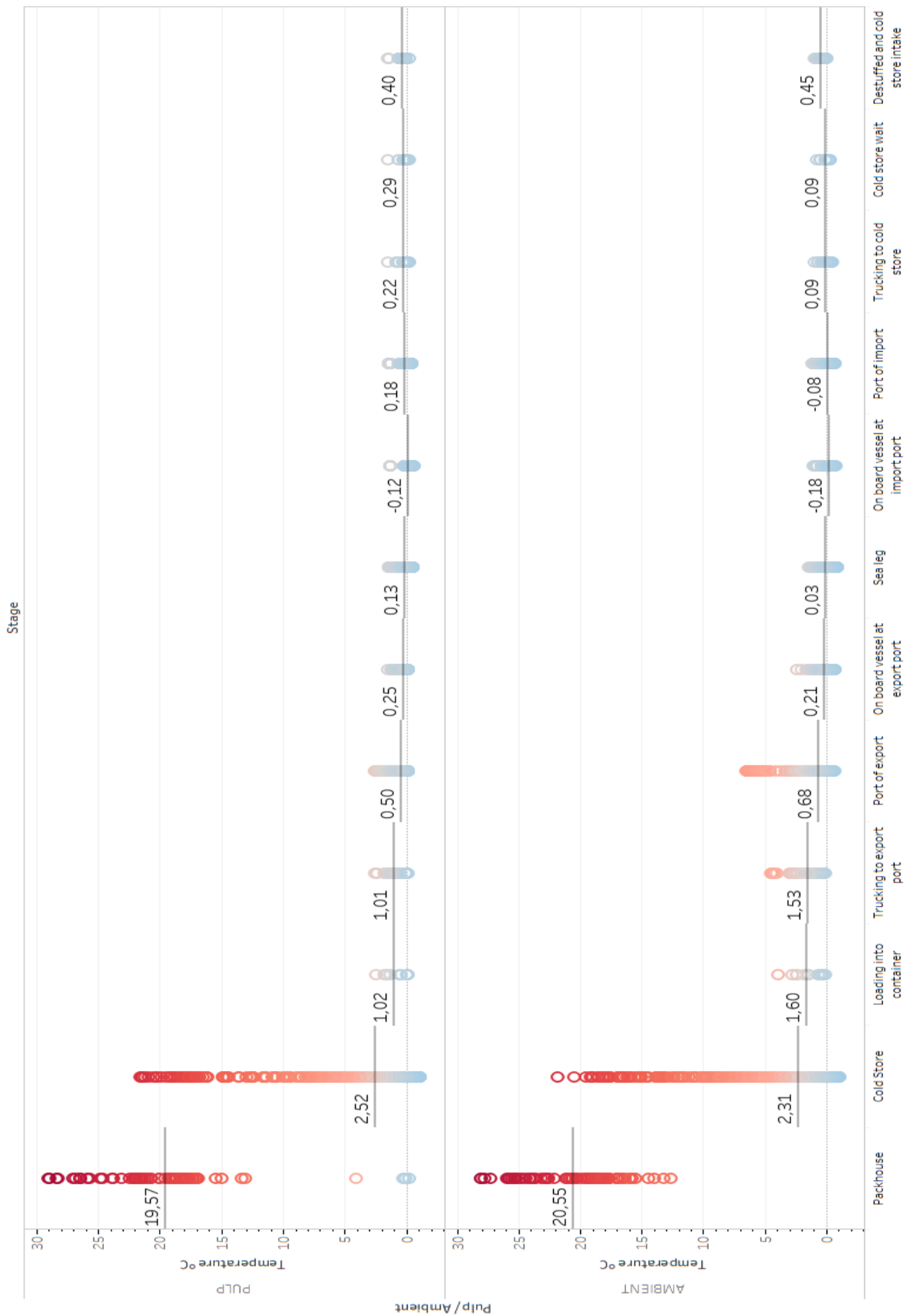


Figure 5.16 Table grape trials collective temperature profiles with median temperature per stage

Table grapes collective pulp and ambient temperature profiles

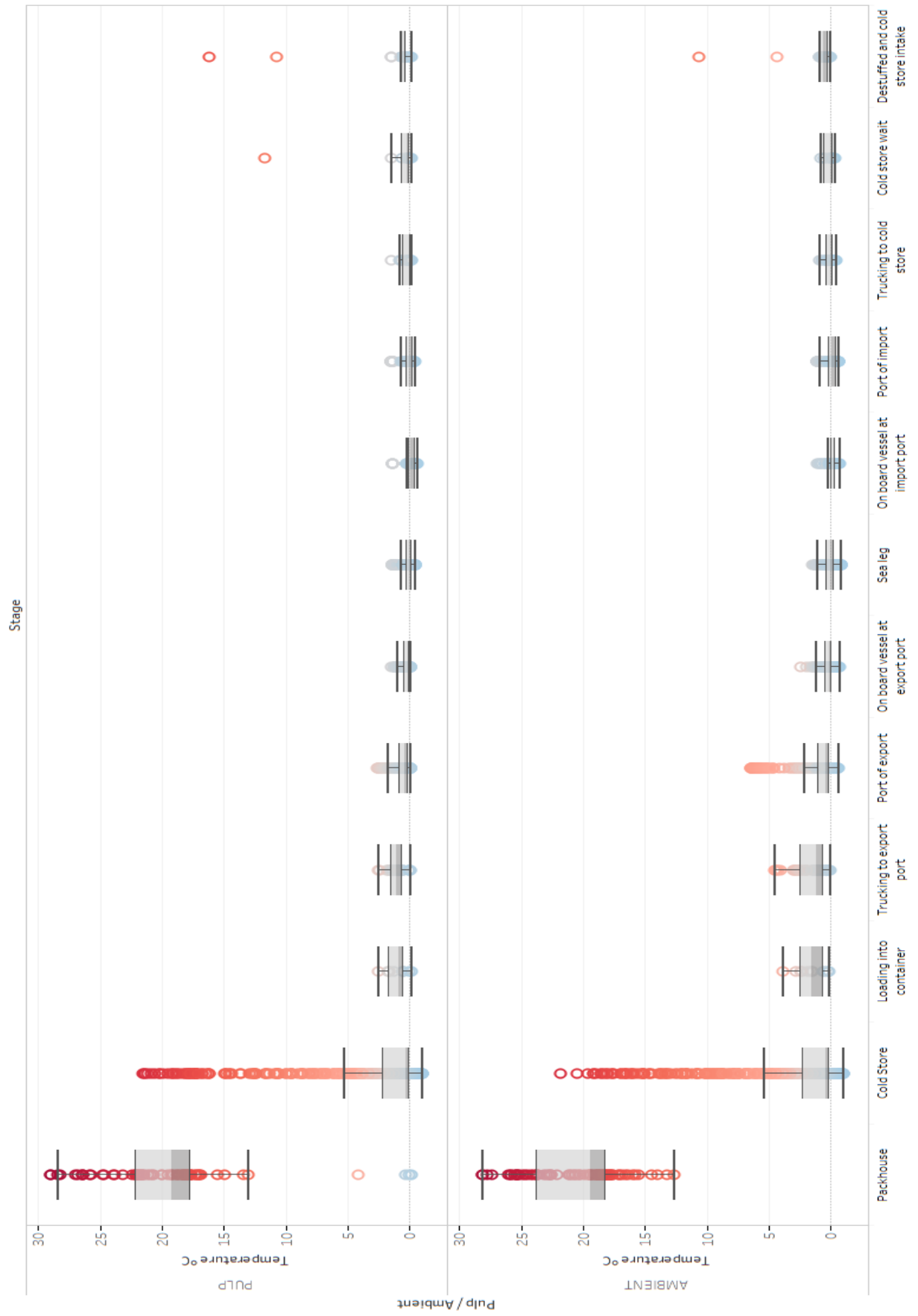


Figure 5.17 Table grape trials collective temperature profiles box and whisker plots

5.6.2.1 *Section one: SA Farms*

Section one consists of the 'pack house', 'cold store' and 'loading in container' stages. The pack-house stage encompasses all the processes the table grapes undergo after the crates of grape bunches are placed on the conveyer belt. These include actions such as sorting, trimming, weighing and packing punnets and cartons.

The cold-store stage consists of an initial transport portion from the pack houses to the cold store facilities as well as the FAC and cold storage prior to staging. It should be noted that for the majority of containers, the initial transport to the cold store from the pack houses is negligible as the journey to cold store A is less than five minutes. Three containers, however, were sent to Cold store B, which is approximately a three hour journey.

The loading-of-container stage includes the movements of the cooled pallets from cold storage, via gas powered forklifts, to the staging area as well as the actual loading of those pallets into the container. Hereafter, the containers are closed, sealed and connected to trucks ready to exit the cold store facility. The stage concludes prior to the trucks gate-out time from the cold store.

When looking at all eleven containers collectively, it was noted that the ambient starting temperatures tended to be approximately between 2°C to 3°C warmer than that of the pulp starting temperatures. The hottest starting pulp temperature recorded was 29.28°C by logger L11 Pulp Middle in container nine. The hottest starting ambient temperature recorded was 30.33°C by logger R5 Middle in container one. The majority of the containers remain on a steadily decreasing temperature trend initially with the exception of container four. Container four experienced a short decrease in temperature, for approximately 20 hours 30 minutes after its arrival at the cold store. Hereafter, the top and bottom layers of the pallets continued on their downward temperature trend, but the temperature of the middle layers began to rise. The middle pulp loggers L1 and R1 recorded temperatures of 14.89°C and 14.33°C respectively during this spike. The ambient middle loggers of pallets L6, L11 and R9 recorded temperatures similar to those of the pulp loggers at 14.33°C, 14.94°C and 14.5°C respectively. The ambient logger R5 Middle was the only middle logger to record a lower temperature of 10.5°C, but it also recorded the same spike as the others as can be seen on Figure 9.14 in the Appendix C. Container four continues on a somewhat

turbulent downward temperature trend until the next section, while containers two and five had problematic initial sections.

Container two experienced three major temperature spikes within the first section. These breaks occurred on 17, 18 and 19 February 2018. The first break was followed by two smaller spikes and this pattern repeated itself in the case of the third major spike. The top and bottom layers of the pallets were the most responsive of the layers during the temperature breaks with the bottom layer mimicking the top, but at lower temperatures. The middle layer of cartons experienced a delayed and more gradual increase in temperature, but remained within protocol range. After the second major spike, loggers L6 Middle, L6 Bottom R9 Middle and R9 Bottom recorded a drop in temperature lower than the rest of the container. There is a possibility of slight chilling injury as all four loggers recorded temperatures below protocol for between 11 and 23.5 hours. The coldest temperature recorded was -2.11°C by logger L6 Bottom. Furthermore, just prior to loading, container two experienced a final temperature spike recorded by all its top loggers and logger R1 Bottom between 02:30 and 03:00 in the morning on 20 February 2018. Logger R9 Top recorded the highest temperature of 8.06°C . There was a slow decrease in temperature with the break concluding later that same day at approximately 16:00.

Container five had two loggers, namely L6 Bottom and L11 Bottom spike at the middle of the cold-store stage. The average temperatures of the spikes were 2.42°C and 2.51°C for 17.5 hours and 15.5 hours respectively. There was a slow rise in temperature hereafter by all of the loggers that remained within range. The majority of loggers recorded an extended temperature break that began at the very end of the cold-store stage and continued through the container-loading stage, trucking-to-export-port stage and into the port-of-export stage before concluding.

More than half of the probed containers experienced temperature spikes and breaks during the loading-into-container stage. Only containers two, eight, nine and eleven were unaffected. Containers one, three, four, five and six all experienced temperature breaks that originated in the cold-store stage, extended into the loading-into-container stage and continued further into the subsequent stages. Of these identified containers, containers four, five and six were the most effected as both containers four and five had thirteen, while container six had eleven, of their eighteen temperature monitoring

devices register temperature breaks during this stage. The highest temperatures recorded in these containers during this stage was 5.11°C by logger R1 Top, 6.06°C by logger L1 Bottom and 4.11°C by logger R9 Top respectively.

5.6.2.2 *Section two: SA Transport*

Section two consists of the 'trucking to export port' and 'port of export' stages. The trucking-to-export stage begins with the loaded containers weight-out date and time when the truck exits the cold store premises. The stage ends just prior to the gate-in time at the port of export, namely, the Port of Cape Town.

The port-of-export stage begins with the gate-in time at the port of export and concludes just prior to when the container is loaded on board the vessel. This stage includes the containers movements within the port itself, such as when the containers were placed into the stacks as well as removed from the stacks and placed quay side prior to loading.

All of the containers experienced a spike or temperature break at the start of section two with varying severities, durations and number of loggers affected. The starting point of the breaks also differed as some originated in section two, while others originated within a previous stage and continued into the following stage, as mentioned at the end of section one: SA Farms. This is visibly seen as the spikes on the *Statistica* graphs around the gate-in and actual time of departure (ATD) dates and times.

In addition, a trend of the first half of the trials, with the exception of container two, experiencing a higher number of breaks within section two: SA Transport was noted. The worst affected containers were containers four, five and six as well as containers three and ten to a lesser extent.

Container four's internal temperature steadily began decreasing after the spike that originated at the end of section one and continued into section two. Logger L11 Middle, however, first incrementally increased in temperature for an extended period of time. It remained at around 4°C for approximately 30 hours before slowly decreasing and only coming back into protocol range once at sea.

Container five experienced a continuous rise in temperature that originated in section one: SA Farms, towards the end of the cold-store stage. This rise in temperature continued throughout the container with the top cartons experiencing the highest

temperatures followed by the bottom and then middle layers. The highest ambient temperature of 8.61°C was recorded in the top layer by loggers R1 Top and L1 Top. It was closely followed by the bottom layer with logger R1 Bottom recording a maximum temperature of 8.11°C. In the middle layer, a maximum temperature of 6°C was recorded by logger L1 Middle, while the pulp logger L6 Pulp Middle recorded its maximum temperature of 2.89°C. The duration of this break was extended as it lasted approximately 64 hours before all loggers were within protocol range again.

Container six also experienced the start of its temperature breaks towards the very end of section one: SA Farms with a maximum temperature of 4.56°C reached by logger L11 Top. There was a defined temperature break at this point in both the top and bottom layers, while the middle layer had a slightly delayed rise in temperature and to a lesser degree. After the peak of the temperature breaks, there is a decrease in temperature. However, there is a large disparity and variability between the temperatures of the layers from this point forward. The majority of the top cartons remain at temperatures of just under 2°C, followed by the bottom cartons and then middle cartons. It was also noted that the majority of the cartons remained above 0°C for the duration of the journey.

Containers three and ten experienced spikes and temperature breaks at the same areas. Container three experienced its first temperature break, which originated at the end of the previous section and continued into the trucking and port-of-export stages, with logger R5 Top reaching a maximum of 6.61°C during the break. All of the top and bottom temperature monitoring devices as well as the pulp middle temperature monitoring devices in pallets L11 and R9, recorded temperature breaks. All the devices, with the exception of logger R5 Top, remained under 4°C during the temperature break. All temperature monitoring devices then returned to temperatures below 2°C and within protocol range. Container ten also experienced its first break originating in previous section, but during the loading-into-container stage. Furthermore, container ten had seven of its twelve loggers record the temperature break temperature rise to over 4°C with R9 Top reaching a maximum of 5.06°C. All temperature monitoring devices recorded a decrease in temperature after the initial break, but none of the devices went below 0°C. Furthermore, loggers R1 Top and R9 Bottom only just went below 2°C for one hour before rising in temperature once more.

The second temperature break experienced by container three was just prior to the container being loaded on board the vessel and extended slightly into that stage. There was an overall rise in temperature by all the temperature monitoring devices with only L11 Top, R5 Top and R9 Top recording a break. The highest temperature recorded during the second temperature break was 3.5°C by logger R5 Top, which is lower than in the first temperature break. Once again, all temperature monitoring devices then returned to temperatures below 2°C and within protocol range. Container ten also experienced its second temperature break just prior to loading on board the vessel and extended into the subsequent two stages. All of the temperature monitoring devices recorded an overall rise in temperature with nine loggers recording a temperature break. The peak temperature of the second temperature break was similar to the first, with loggers R1 Top and R9 Bottom both recording a maximum temperature of 4.695°C. Loggers R1 Top and R9 Bottom remained warmer than the rest of the container for the remainder of the journey.

5.6.2.3 Section three: Sea Leg

Section three consists of the 'on board vessel at export port', 'sea leg' and 'on board vessel at import port' stages. The on-board-vessel-at-export-port stage begins when the container is loaded on board the vessel prior to the vessel's actual time of departure (ATD). The sea-leg stage begins when the vessel exits the port of export, indicated by its ATD. It includes the sea transit part and concludes at the vessel's actual time of arrival (ATA) at the port of import. The on-board-vessel-at-port-of-import stage is simply the reverse of the on-board-vessel-at-port-of-export stage. It begins at the vessel's ATA at the port of import, continuing until the point just prior to the container being off-loaded.

All of the containers experienced an increase in temperature, to varying degrees, just prior to the containers being loaded on board the vessel. The majority of the containers thereafter experienced a decrease in temperature and remained within protocol range, with minimal upsets, for the remainder of the journey. Containers one and ten experienced temperature breaks in the previous sections with the after effects continuing for the remainder of the export journey. There were, however, no additional changes or temperature breaks experienced by these containers. In container one, pallets L11 and R9 continued to have higher temperature profiles, across all layers, in comparison to the other pallets, after the initial temperature break originating at the

end of section one. Container ten had a similar trend, but with loggers R1 Top and R9 Bottom having higher temperature profiles than the remaining loggers after the temperature breaks recorded in section two: SA Transport.

Containers two, six and eight also experienced temperature breaks that originate in previous sections with the after effects continuing for the remainder of the export journey. However, these containers did experience temperature fluctuations during section three: Sea Leg. Container two had erratic temperature fluctuations during section three: Sea Leg, especially during the first half of the sea-leg stage. The top cartons were the worst affected. The maximum temperature recorded was 1.97°C by logger L11 Top, while the minimum temperature recorded was -1.17°C by L6 Bottom. The fluctuations were within the protocol temperature range, but the number of fluctuations is concerning.

Container six had a large disparity and variability between the temperatures of the three layers within the container, as explained in section two: SA Transport. This continued from section two: SA Transport for the remainder of the export journey. During the sea leg, loggers L6 Top, L11 Top and L6 Middle were still recording extended temperature breaks originating in the previous section. At approximately 10:30 AM on 14 March 2018, loggers L1 Top and R5 Top also recorded an extended temperature break and remained above 2°C until approximately 10:00 PM on 17 March 2018. During approximately this same timeframe, there was a brief dip in temperature recorded by the majority of bottom layer cartons, but with no lasting effect. Logger L11 Pulp Middle also experienced an extended temperature break at approximately 01:00 AM on 20 March 2018, which extended with loggers L6 Top, L11 Top and L6 Middle into the next stages.

Container eight does not have such a large disparity between its loggers as container six, but pallets L1, L11 and R9 remain the warmest, post section two: SA Transport breaks, for the rest of the export journey. The bottom and middle layers remain somewhat constant, with relatively smaller temperature fluctuations, with the exceptions of the middle loggers of pallets L1, L11 and R9. These fluctuations are within protocol range. The top layer also experiences temperature fluctuations that are within protocol temperature. However, there are more temperature fluctuations, which are more erratic and at a warmer temperature than experienced in the other layers.

5.6.2.4 *Section four: UK Transport*

Section four consists of the remaining four stages, namely the 'port of import', 'trucking to cold store', 'cold store wait' and 'destuffed and cold store intake' stages.

The port-of-import stage begins from the point of the container being off-loaded from the vessel, until it was loaded onto a truck prior to gate-out. The next stage, trucking-to-cold-store stage, starts with the gate-out date and time and encompasses the reefers transport journey to the cold store facility where it concludes with the cold store arrival time. The cold-store-wait stage is the possible delay from when the container arrives at the cold store prior to it being attached to a dock and destuffed. This length of time may vary due to various reasons. The final stage, namely, destuffed-and-cold-store-intake stage, begins when the container is attached to a dock, the doors are opened and all the pallets removed and concludes at the time all the devices were collected. The devices were collected shortly after the containers were destuffed.

There are no new temperature breaks that occur during section four: UK Transport. There are, however, temperatures that are higher than protocol temperature and lie outside of the acceptable tolerance range as a result of temperature violations in previous sections.

5.6.2.5 *Findings summary*

When looking at all eleven containers collectively, it was noted that the top layer of cartons tended to be the warmest of the three recorded layers. The top layer also tended to be the most reactive and volatile layer during temperature fluctuations in the majority of the containers. The bottom layer tended to be the second warmest layer and often mimicked the top layer, but at a slightly lower temperature. The middle layer tended to experience changes in temperature at a delayed rate and to a lesser extent if they were experienced. Furthermore, if the middle layer did gain heat during temperature fluctuations, it took much longer to dissipate the heat than the other layers, if it was dissipated at all. In addition, there was a slight tendency of the left side of the container to be marginally warmer than the right.

A typical table grape container journey started with high temperatures as the table grapes came into the pack house after harvesting. Hereafter, there was a decrease in temperature due to the cooling taking place at the pack house and cold stores. There was a rise in temperature with a distinct spike in and around the gate-in time and date.

This was always followed with a further spike in and around the ATD date and time. The first spike often started around the loading-into-container or trucking-to-export-port stage, while the second usually started when the container was loaded on board the vessel. The temperature profiles of both the pulp and ambient temperatures remained relatively stable from approximately the middle of the sea-leg stage until the conclusion of the cold chain with no new temperature breaks originating in the final section, UK Transport.

This held true for all of the containers in essence. There was a trend that the first half of the containers experienced more temperature breaks, not only more at initial stages of the export cold chain, but also with more loggers affected at these stages in comparison to the second half of the containers. Furthermore, containers one to six experienced the temperature breaks at higher temperatures. After the temperature breaks, these containers remained constant at higher temperatures in comparison to the second half of the containers. This can further be seen in the device break table summary shown in Table 5.13 when looking at the total number of breaks experienced per container. There were also issues regarding the quality of the table grapes, once they had arrived in the United Kingdom.

The receiving UK DC, DC1, has a traffic light quality grading system in place with their QC department during unloading and intake of new stock. The traffic light system determines approximate shelf life. Red status results in no storage life, amber status results in up to eight days storage and green status is up to fifteen days storage. The number of reports per container and their statuses are shown in Figure 5.18. The quality reports status of incoming containers progressively became worse, especially towards the end of the season as the later shipments were ranked 'RED'. Figure 5.19 illustrates the table grape varieties and the number of corresponding quality reports.

When looking at the length of time spent at certain stages during the cold chain of the eleven containers, it is evident that there is room for improvement. The average time spent in the pack house is approximately 07 hours 40 minutes before the pallets are moved to the respective cold stores. This is longer than the recommended 6-hour window. It should be noted that the average time spent in the cold stores was between 2 and 4 days, but container eight spent 07 days 02 hours and 19 minutes in the cold store.

Further concerns were the duration of time containers spent in the Port of Cape Town. It ranged between 01 day 16 hours 41 minutes and 07 days 12 hours 18 minutes. The majority of the containers that spent an extended time in the port of export were the first half of the containers. Furthermore, the first half of the containers, which experienced a greater number of temperature breaks, spent a longer time in port than the second half.

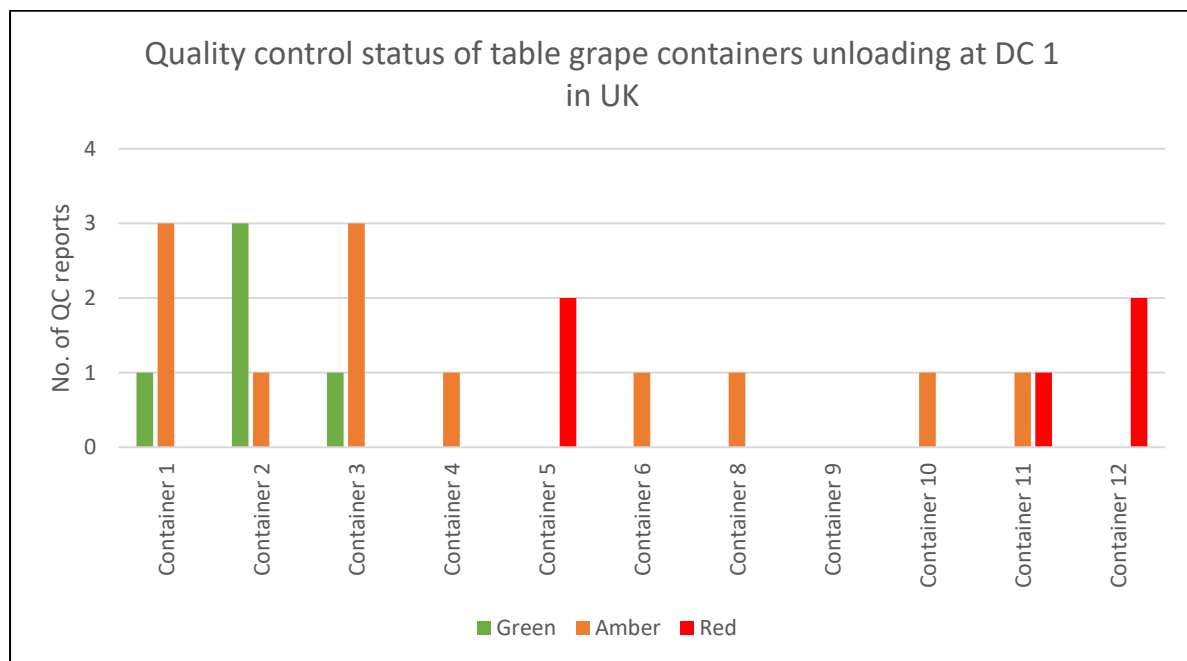


Figure 5.18 Quality control status of table grape containers at DC1 in UK

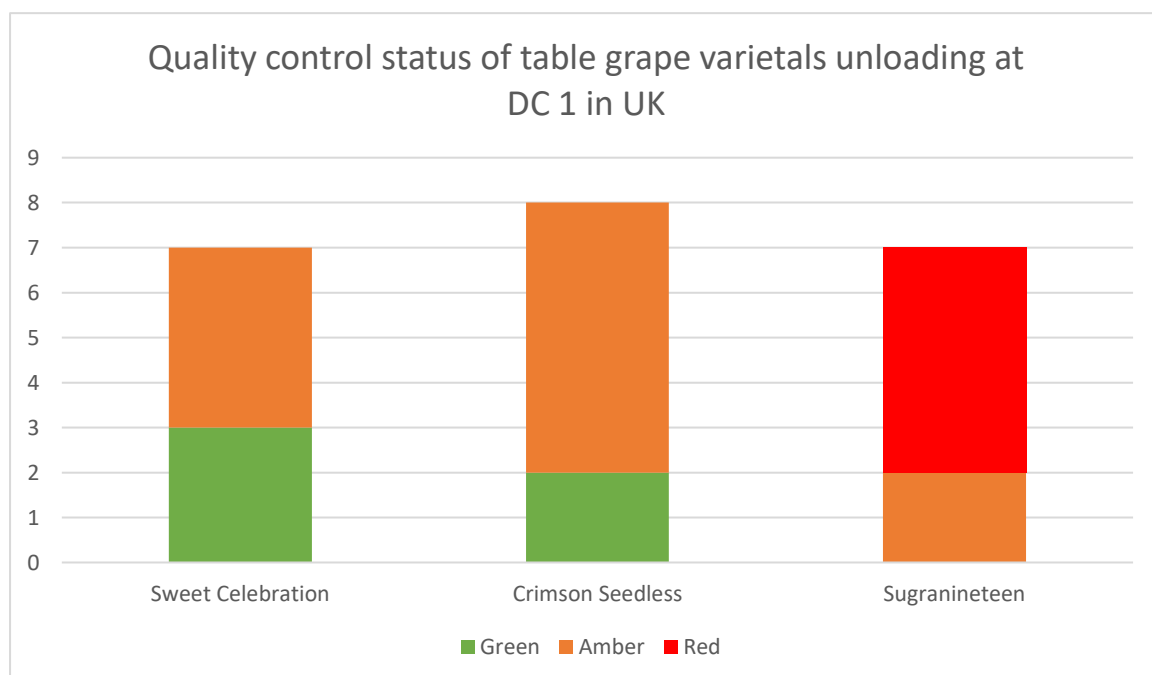


Figure 5.19 Quality Control status per table grape containers per varietal at DC1 in UK

5.7 Research reliability and validity

Reliability and validity are two of the most prominent measures of research quality (Bryman & Bell, 2015 and Middleton, 2019). Reliability of research is concerned with the consistency of the measure and the extent to which the results can be reproduced if retested under the same conditions. Validity is concerned with the accuracy of the measure and if the method measures what it was intended to (Bryman & Bell, 2015 and Middleton, 2019).

The reliability of this research can be tested by the test-retest type of reliability (Bryman & Bell, 2015 and Middleton, 2019). The temperature trials conducted during this research are a well established methodology that has been proven through previous research. It is also a widely accepted test method within the deciduous fruit industry that is often mirrored by many role players' internal control measures.

The validity of this research can be measured on both content and concurrent validity evidence (Bryman & Bell, 2015 and Middleton, 2019). Regarding content validity, the constructs and variables used in this research have also been used in previous temperature trial research conducted in the deciduous fruit industry by academics and industry experts. Furthermore, Company X is a prominent international fruit exporter with years of experience in the industry. When Company X prompted the research, their expertise in the industry was shared with the researcher. The concurrent validity was proven through feedback received on the research from Company X, industry experts and academic professionals.

6 Interpretation of results

6.1 Introduction

This chapter interprets the results and graphs illustrated in chapter 5, data analysis. The results and possible reasons for the outcomes of the data are suggested per fruit kind.

This chapter highlights and focuses on the most important trends and findings of the previous chapter. The findings of the three trials are interpreted and reasons for the data outcomes discussed.

6.2 Main findings derived from temperature break analysis

Collectively speaking, the results confirmed suspected hot spot areas of the export cold chains, such as at gate-in, ATD and ATA, as well as within a container, at the doors. With reference to the physical fruit, table grapes are the most temperature sensitive fruits in this research largely due to their non-climacteric nature as elaborated on in section 3.6.1. In essence, some fruits, such as table grapes, immediately begin to decay once they are harvest from the vines and so must be harvested when perfectly ripe. Other fruits, such as apples and pears can continue to ripen after they have been harvested and can therefore be picked while unripe. Consequently, table grapes have a shorter lifespan than apples and pears. This in turn, makes table grapes more sensitive to temperature breaks as they immediately begin to decay instead of continuing to ripen fully and then decay.

Regarding the pome fruits, the pears, due to the Abate Fetel varietal characteristics, are more temperature sensitive than apples. Another important factor relevant to this research is the persistent drought that has affected South Africa, particularly the Western Cape, since 2015. The abnormal heat and reduction in water allocations to agriculture in the drought-stricken production regions not only impacted the harvest, but had detrimental effects on the plants themselves (Western Cape Government, 2017:26).

6.3 Pome

Both the apple and pear trials experienced similar issues during the exporting process at the same points along their cold chains. Furthermore, due to the fact that their cold chains are identical from the port of export onwards, it was decided to discuss their

cold chains collectively. For the purposes of this research and the analysis thereof, a cold chain temperature break was defined as, “every instance in which the temperature readings rise higher than 2°C or drop lower than -1.5°C (or -1°C in the case of pears) for longer than 90 minutes” (Fresh Produce Exporters’ Forum, 2016:105, Freiboth, Goedals-Gerber, Van Dyk & Dodd, 2013 & Goedhals-Gerber, Haasbroek, Freiboth & Van Dyk, 2015).

Suspected hotspot areas for temperature breaks were highlighted and confirmed. Other areas of concern were also brought to light. In total, five major areas of concern were highlighted with a sixth to bear in mind.

In addition, there was one container from both the apple and pear trials that was suspected of having a container malfunction. Container eleven in the apple trials experienced a prominent and rapid rise in temperature at approximately the half way point of the sea leg. Also, at approximately this point in the pear trial of container six, an extended, but incrementally increasing rise in temperature was experienced. Both of these temperature breaks were recorded for longer than a day.

6.3.1 Apples

Regarding the apple trials, a total of 57 container temperature breaks consisting of 371 temperature monitoring device temperature breaks were analysed. All of the five containers experienced multiple temperature breaks during the trials. The majority of temperature breaks took place during the first stage of the first section of the cold chain, namely, the pack-house-and-cold-store stage. The pack-house-and-cold-store stage accounted for 203 of the 371 temperature breaks. Thus, approximately 55% of all the temperature breaks recorded during the trials. Furthermore, the vast majority of these breaks lasted for extended periods of time, often for longer than a day. Figures 6.1 and 6.2 illustrate the durations and stages of the temperature breaks further.

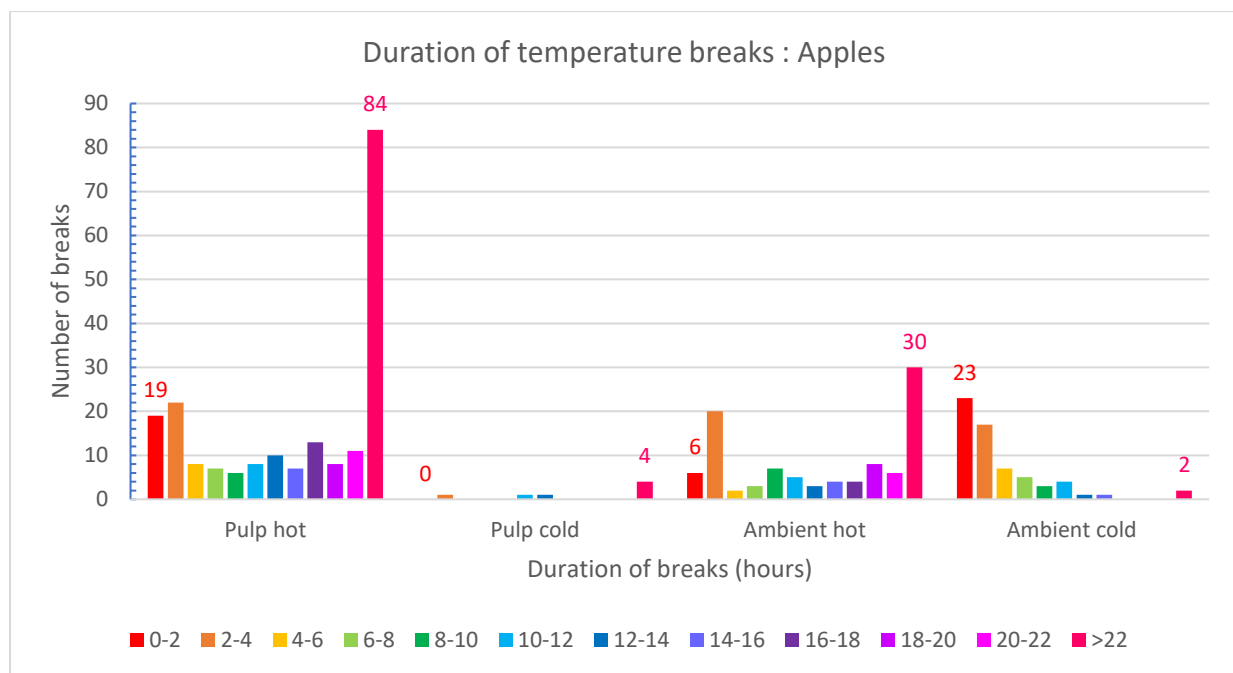


Figure 6.1 Duration of temperature breaks: Apple trials

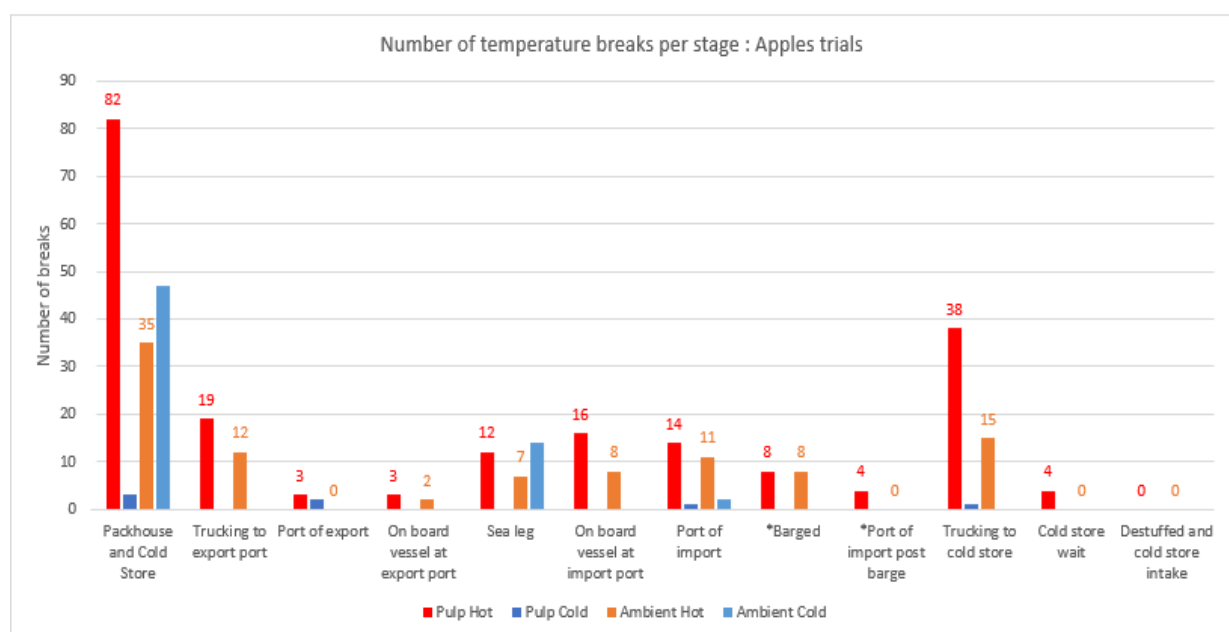


Figure 6.2 Number of temperature breaks per stage: Apple trials

6.3.2 Pears

A total of 69 container temperature breaks consisting of 371 temperature monitoring device temperature breaks were analysed for the pears section. All of the five containers experienced multiple temperature breaks during the trials. The majority of temperature breaks took place during the first section of the cold chain, during the first stage namely, the pack-house-and-cold-store stage. The pack-house-and-cold-store

stage accounted for 220 of the 371 temperature breaks. Thus, approximately 59.3% of all the temperature breaks experienced during the trials. Furthermore, the vast majority of these breaks lasted for extended periods of time, often for longer than a day. Figures 6.3 and 6.4 illustrate the durations and stages of the temperature breaks further.

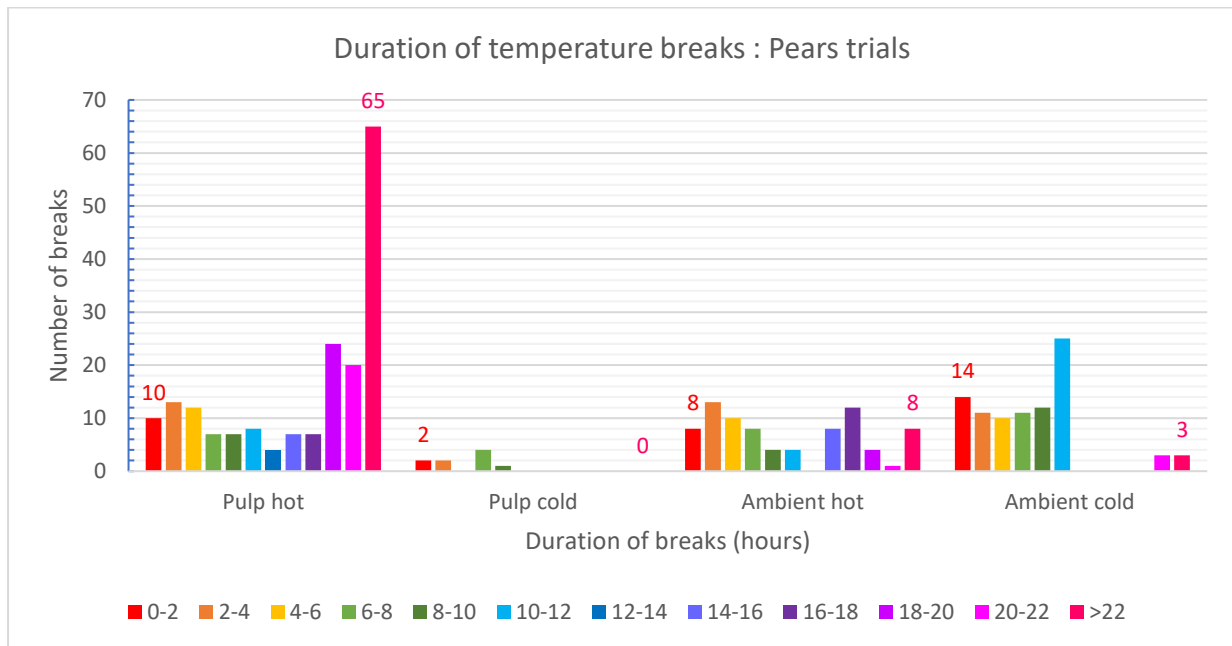


Figure 6.3 Duration of temperature breaks: Pear trials

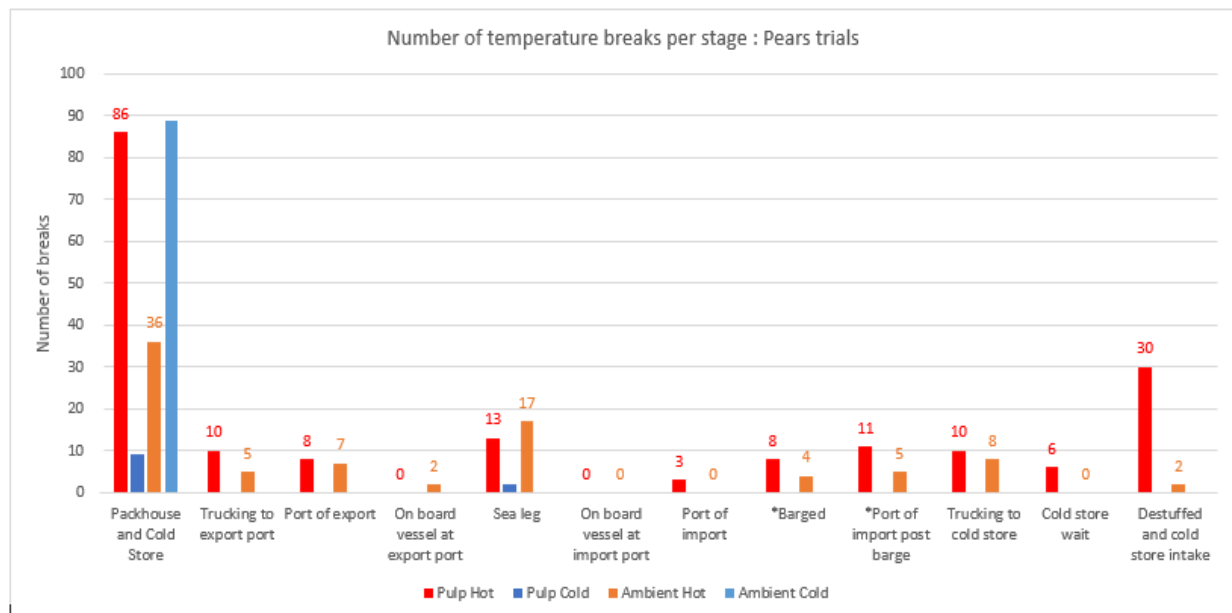


Figure 6.4 Number of temperature breaks per stage: Pear trials

6.3.3 Concern 1: The drought

Firstly, the ongoing drought in South Africa as well as its long-term effects need to be kept in mind. Although the impacts of the drought can differ greatly between production regions and even between neighbouring farms, the Western Cape region has experienced particularly devastating effects. Due to the extreme heat, low dam levels and all-round water restrictions, water allocation for agricultural use was heavily restricted. The drought and contributing factors such as severe sunburn, has impacted the longer term health of the fruit trees. Due to the acute stress experienced by the trees, the flowering process was weaker and the flowers were of poorer quality (Steenkamp, 2018). Even if the tree survives the drought period, it could take years to fully recover and produce at its full capacity once again. In addition, if orchards need to be replaced, it can take up to five years for the new orchard to come into production. Thus, the impacts of the drought on the plant health and fruit quality could last for between 5 and 10 years (Western Cape Government, 2017:28).

6.3.4 Concern 2: High starting temperatures

All of the apples and pears started with high pulp and ambient temperatures. This is greatly concerning as the apples and pears had been removed from cold storage, where they were kept at protocol temperature of -0.55°C , prior to going through the pack house for further processing via the water bath. It should be noted that the apples were removed long term cold storage, while the pears were removed from regular cold storage. The water used in the water bath is tap water with additives if required. Relatively cool tap water is approximately 16°C . Thus, despite the water bath's temperature being cool and even cold to the touch, it is far warmer than the core temperatures of the fruits submerged in it. This temperature difference led to the apples and pears absorbing heat from the water bath of more than 10°C on average and in the worst case of more than 18°C in pulp temperature. The temperature fluctuations of more than 10°C would have doubled or even tripled the respiration rate of the fruit (Silva, 2010) as explained in section 3.6.1.1. This would result in implications of reduced shelf life as well as quality implications of post-harvest microbial growth. This was noted in pear containers five and six as they had major quality control issues with mould growth and in apple container nine that experienced a major quality control issue with decay.

Despite the high starting temperatures, the pulp and ambient temperatures relatively quickly decreased to within protocol range once in the cold stores. It was noted that the temperatures of the pears decreased much quicker than those of the apples. Furthermore, it was also noted that the bottom cartons reached the lowest temperatures during this initial decrease in temperature.

6.3.5 Concern 3: Staging and loading of containers

There was an incremental, yet steady increase in both the ambient and pulp temperatures during the staging and loading process for both apples and pears. As the pallets were removed from the cold store, they were placed onto concrete floors, which despite being under a roof, still receive varying amounts of sunlight throughout the day. This less intense winter sun heated the concrete floors, which in turn retained this heat, throughout the day. When the cooled pallets are placed on the warmer concrete floor, the heat is absorbed by the closest fruits in the bottom cartons. This heat transfer increases the temperature of the fruit and in turn begins to increase the fruit's respiration rate. As the fruit's respiration rate increases, the fruits generate their own additional heat in conjunction with the heat gained from the concrete floor. Thus, even after the pallets have been removed from the concrete floor and loaded into the reefer containers, the fruits themselves in the bottom cartons are still generating their own heat due to their increased respiration rates. It is very important to note that a reefer container is not built to cool down warm or hot contents, but rather to maintain the already cooled products at a specified temperature (Fresh Produce Exporters' Forum, 2016:115). Consequently, it is from this point forward that the bottom cartons remain the warmest layers until the conclusion of the export cold chain, as the fruits in these cartons could never dissipate the initial heat gained, nor fully lower their respiration rates. It should also be kept in mind that the bottom cartons were the warmest layer throughout the export cold chain, despite being the coolest during the cold store phase of the pack-house-and-cold-store stage. This indicates that the heat was gained during the staging and loading of the containers.

Furthermore, this latent heat gained caused the respiration dissimilarity between the pallet layers to develop further as the cold chain progressed. It resulted in discernible temperature disparities in three main areas; firstly, between the layers within the same pallet, secondly, between different pallets within the container as a whole and thirdly,

overall erratic temperature profiles and fluctuations for the remainder of the export cold chain.

6.3.6 Concern 4: Gate-in

The rise in temperature recorded in and around gate-in had its origins during the container loading process, due to the delayed nature of temperature breaks, as there was a gradual increase in overall temperatures. This often worsened during the trucking-to-export-port stage, where it often culminated in a temperature break. This temperature break continued into the next stage, the port-of-export stage, after the gate-in point before it finally concluded. This rise in temperature was reflected in both the pulp and ambient temperatures recorded. It was from this point onwards that both the pulp and ambient average temperatures remained warmer throughout the duration of the export cold chain until its completion in The Netherlands. The pear trial containers had a tendency of experiencing the temperature breaks for a little bit longer than the apples did.

In addition, after the initial increase and then subsequent decrease in temperature recorded around the gate-in times, a smaller, second spike was recorded just prior to ATD. This will be discussed in the next section (6.3.7).

Additional reasons for the later temperature spikes and breaks can also be attributed to the port-of-export stage itself, as a result of congestion around as well as within the port and natural delays such as rough sea and wind conditions.

6.3.7 Concern 5: ATD

The second rise in temperature occurred in and around the ATD date and time, at the overlap of the port of export and on-board vessel at port-of-export stage. This rise in temperature was to a lesser degree than the previous spike at gate-in. This temperature spike had its origins during the loading process of the container on board the vessel. As the containers were unplugged from the stacks and transported quay side for loading, there is no longer cooled air circulating through the container. Due to the heat gained by the bottom cartons during the container loading process, these fruits immediately began to respire at an incrementally increasing rate. Temperatures did increase in all containers, but only resulted in temperature breaks in containers one and two. Those temperature breaks also did not exceed 3°C. Once the containers were loaded and plugged into the vessels power supply, there was a slight decrease

in overall temperatures. This drop brings the containers closer to the protocol temperature of -0.55°C , where it should ideally remain for the entire journey. Once the vessels had sailed, fluctuations in both pulp and ambient temperatures were recorded. The fluctuations in containers four and six were particularly erratic, while containers one, two and five remained somewhat stable. All of the containers did however, have large disparities between pallet layers as seen in the wide spread of the time series lines in Appendices A and B, Figures 9.1 through 9.10.

The erratic temperature profiles of the pome fruits in conjunction with the layer disparities were also impacted by the containers defrost cycle. Collectively, the container's inability to decrease the fruit's temperatures to the specified protocol temperature, the increased respiration rate particularly in the bottom cartons and the additional heat generated as a result, had a knock-on effect in the port of Rotterdam.

6.3.8 Concern 6: Post ATA

There were typically three possible increases in temperature recorded post the ATA of the vessel at the port of import. The first spike occurred when the containers were offloaded from the vessel. This, in essence, is the reverse of what occurred in the Port of Cape Town. The containers were unplugged from the vessel's power supply during the offloading process, whereafter they were plugged back into a power source at the stacks. Due to the already increased respiration rate of the bottom cartons and the temporary suspension of cooled air circulating through the pallets, temperature breaks often occurred as a result.

The second spike in temperature occurred during the barge stage of the cold chains and was not applicable to all the containers. Only containers two, six, eight and nine were barged. This rise in temperature occurred for the same reasons as the first, as the containers are not plugged into a power source during the barge stage. Once again, temperature breaks occurred as the already increased respiration rate of the bottom cartons and the temporary suspension of cooled air circulating through the pallets resulted in a domino effect. The respiration rate of the bottom cartons increased further and generated additional heat. This heat would then begin to warm the adjacent cartons, slowly increase those fruits' respiration rate and so on.

A third rise in temperature was noted at the end of the cold chain. This was during the unloading of the container where the container doors were opened and devices removed.

Container twelve experienced a large temperature break, with Logger L11 Bottom recording a maximum temperature of 9.421°C. The majority of the breaks lasted for 50 hours or more with the longest break lasting 80 hours. It was observed that chassis often stood with containers waiting at DC3 without a truck to provide a power source. This resulted in the domino effect described earlier, to occur again.

6.4 Table grapes

A total of 53 container temperature breaks consisting of 440 temperature monitoring device temperature breaks were analysed for the table grapes section.

For the purposes of this research and the analysis thereof, a cold chain temperature break was defined as, “every instance in which the temperature readings rise higher than 2°C or drop lower than -1.5°C (or -1°C in the case of pears) for longer than 90 minutes” (Fresh Produce Exporters’ Forum, 2016:105, Freiboth, Goedals-Gerber, Van Dyk & Dodd, 2013 & Goedhals-Gerber, Haasbroek, Freiboth & Van Dyk, 2015).

All eleven containers experienced multiple temperature breaks during the trials. The majority of temperature breaks took place during the first two stages of the first section of the cold chain, namely, the pack-house and the cold-store stages. The pack-house and cold-store stages accounted for 350 of the 440 temperature breaks. Thus, approximately 79.5% of all the temperature breaks recorded during the trials. Furthermore, the vast majority of these breaks lasted for extended periods of time, often for longer than a day. Figures 6.5 and 6.6 illustrate the durations and stages of the temperature breaks further.

Suspected hotspot areas for temperature breaks were highlighted and confirmed. Other areas of concern were also brought to light. In total, five major areas of concern were highlighted with a sixth to bear in mind.

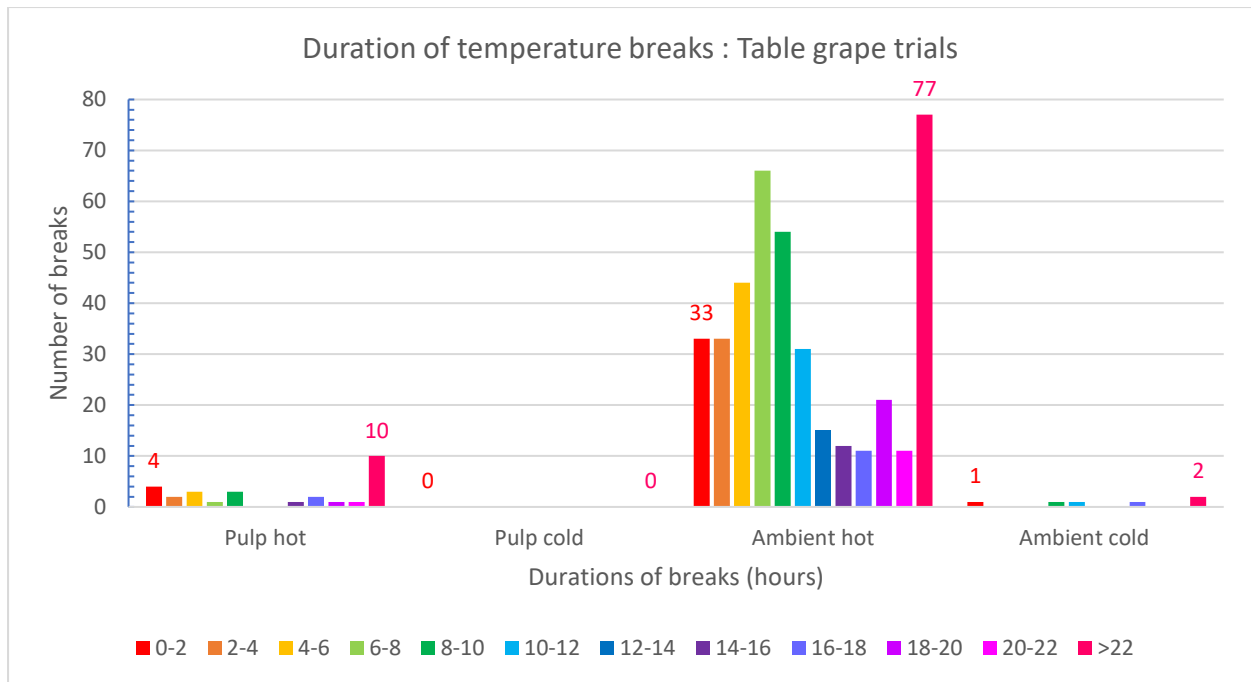


Figure 6.5 Duration of temperature breaks: Table grape trials

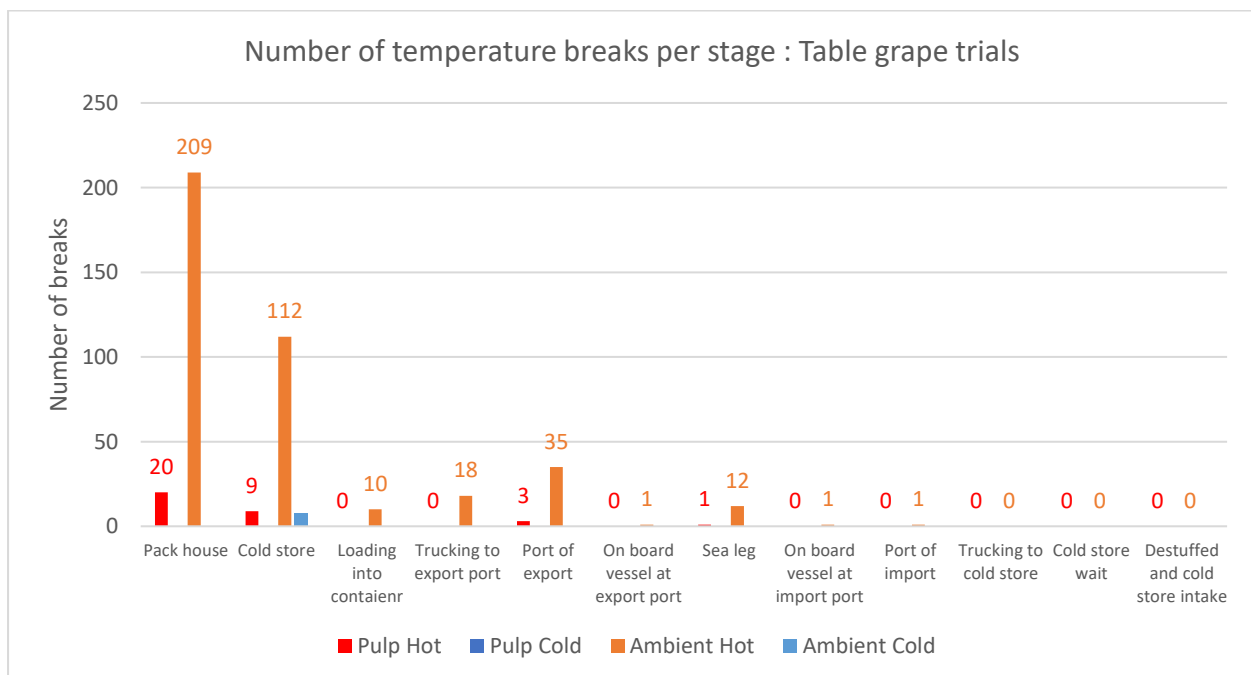


Figure 6.6 Number of temperature breaks per stage: Table grape trials

6.4.1 Concern 1: The drought

As discussed in section 6.3.3, the drought had a particularly devastating effect in the Western Cape region of South Africa with major quality implications especially for table grapes. The Hex River Valley region was one of the hardest hit by the drought with

producers recording a reduction of between 10% - 30% in their harvest volumes in comparison to the previous season (SATI, 2018).

Attributable to the stress experienced by the vines during the drought, due to higher than normal temperatures and water restrictions, the initial quality of the fruit is brought into question. The best fruit was exported in the beginning of the season, but towards the end of the season, the quality was not as high. As fruit volumes were reduced owing to the drought, farmers pushed to export as much as possible in order to break even within their business, even if the fruit was at a slightly lower quality. The quality of the fruit at the start of the export cold chain is the highest it will be throughout the chain owing to the perishable nature of the product. If lower quality products were loaded into the container at the start of the journey, even with a perfect cold chain, the quality would be poorer at the end of the cold chain. This principle is demonstrated with containers eleven and twelve.

Furthermore, higher than average harvesting temperatures could also have affected the rate of respiration of the fruit. The workers would have continued with operations as normal, but the higher outside temperatures would make the fruit respire at a faster rate than usual. Thus, the quality of the fruit could have been affected through no fault of the workers, but rather environmental factors not mitigated sufficiently.

6.4.2 Concern 2: Insufficient cooling of pallets during Forced Air Cooling (FAC)

The second and third concerns both occurred at the cold store. Container four demonstrates the principle of insufficient cooling of the pallets while in the FAC tunnels with its irregular initial decrease in temperature during the cold-store stage. The pallets were cooled, but not for long enough. All the carton's temperatures did initially decrease, but while the top and bottom cartons remained relatively cool, the middle cartons did not. The top and bottom cartons received direct cooling and thus, rapidly lost their heat and remained relatively cool once removed from the tunnels. The middle cartons need the cartons around them to cool and dissipate their heat first before they begin to dissipate their retained heat and begin to cool. The middle cartons are the last to dissipate their heat as they are in the centre of the pallet.

Container four was loaded during the beginning of the trials and thus, at peak production time. Possible reasons behind insufficient cooling of pallets are due to the seasonal rush. There is a limited number of FAC tunnels at each facility and high

volumes of new fruit entering daily. To keep up with demand and optimise throughput, time spent by pallets in the FAC tunnels could have been shortened. Alternatively, the speed of the fans and other such settings used during the FAC process could have been altered to hasten throughput resulting in the middle cartons disparity explained earlier. It should be noted, however, that this was not a very common problem and container four was not the most extreme example, but it is still worth noting as this oversight could have detrimental effects.

In addition, higher peak volumes are being experienced by cold stores owing to different delivery patterns from farmers. Farmers are now able to pack higher quantities of table grapes at a faster pace. This is largely due to improvements in cultivars, such as increasing yields and size. This increase can result in abnormally high peaks during some weeks.

6.4.3 Concern 3: Movement within the cold store from FAC tunnels to cold storage

This issue was noticed in the majority of the containers, but particularly in containers two and five. Not all resulted in temperature breaks, but definite temperature fluctuations and spikes occurred. When the pallets are removed from the FAC tunnels, they are placed into cold storage prior to loading. Ideally, the forklifts should remove the pallets from the tunnels, transport them directly into the cold store area, before placing the pallet in its specifically allocated spot. However, a slight delay is often experienced here. There are various reasons that could result in this process not being accomplished smoothly. An example includes unclear communication instructions and storage errors resulting in pallets being stored in incorrect locations or the wrong pallets being fetched for loading. Often, the pallet could be left outside the cold storage area while the problem is resolved, gaining heat in the interim. This is a cause for concern as temperature breaks are additive in nature (Freiboth *et al*, 2013) and once the temperature of the fruit has started to decrease, it should not increase again.

6.4.4 Concern 4: Staging and loading of containers

There was an overall increase in temperature that originated during this stage and often continued into the next stage, namely the trucking-to-export-port stage. During this stage, the pallets are removed from the cold stores and brought into a staging area where they are arranged as per consignment. This initial staging area is located behind the loading area. As pallets are loaded into containers and the trucks leave,

the next consignment moves from the first staging area to a second staging area just in front of the loading bay door. Depending on what time the containers were loaded and how long the pallets remained outside of the cold storage area, the severity of these temperature breaks and or fluctuations varied. However, the more severe a temperature break, the longer it lasted and the more stages it continued into. In addition, a slight, yet steady decrease in temperature was shown during the trucking-to-export-port stage by some pallets. This was attributed to the longer trucking-to-export-port stage of those containers, as they were connected to the truck's power supply for the journey.

6.4.5 Concern 5: Gate-in

There was a constant increase in the temperature in and around the gate-in time and date. All of the containers experienced a spike or temperature break at the start of section two: SA Transport, with varying severities, durations and number of loggers affected. A few containers had a continuing temperature break that originated during the trucking-to-export-port stage or further back during the loading-into-container stage. Furthermore, the first half of the containers in the trials experienced more temperature breaks than the second half. It should be noted that the majority of the first half of the containers arrived during the afternoon, between 11:26 and 15:41 and spent between 4 to 6 days within the port of export terminal. The majority of the second half of the containers arrived during the morning hours, between 04:38 and 08:05 and spent between 1 to 3 days within the port of export terminal.

Moreover, the arrival times also impacted on the duration of the trucking-to-export-port stage. The journey from Cold store A to the port of export took trucks an average of approximately 04 hours and 02 minutes. Container three achieved the best time of 03 hours and 17 minutes at 04:32 on Thursday morning. Container ten, however, took 05 hours and arrived at 06:03 on Monday morning. These trucks would have had to make use of the N1 highway to enter the port of export. Container three was well ahead of peak traffic times and managed to avoid traffic delays as a result. Container ten was travelling during the beginning stages of peak traffic on the highway and thus, was caught in congestion driving towards the city. Trucks from Cold store B driving to the port of export experienced a similar phenomenon. The journey from Cold store B to the port of export took trucks an average of 02 hours and 08 minutes. Container eight travelled the distance in 01 hour and 21 minutes arriving at 18:42 on Tuesday evening.

Container four took 03 hours and 20 minutes arriving at 15:41 on Friday afternoon. It should be noted that owing to historical town planning and the location of the working port within the commercial waterfront, there is always some congestion in the immediate surrounding areas. This congestion is worsened during peak times for both in-coming and out-going traffic from town. Container eight missed the peak traffic congestion as during its transit time, the majority of the traffic was leaving town. Container four was caught in the start of peak traffic congestion around the port, as it starts earlier on a Friday than during the rest of the week.

Possible reasons for the rise in temperature in and around the gate-in time and date could be due to congestion at the port itself and the delays experienced by the trucks waiting in line to enter port. The congestion would be more severe during traditional working hours and later parts of the afternoon.

Also, once the container arrives at port and is unplugged from the truck to be moved into the stacks, there is often a delay. The container is unplugged from the truck, then transported to the stacks where it can stand for some time before a member of port staff plugs the container into a power source. Furthermore, issues arise during congested times as the work pace increases, allowing for mistakes to occur. The stacks close for a vessel approximately twelve hours before the vessel is set to be loaded (Transnet Port Terminals, 2018:24). As is human nature, many cold chain partners send their containers to the port at the last possible minute, which causes bottlenecks and congestion at the port itself. The overwhelmed port staff frantically try to resolve the bottlenecks and alleviate the congestion, increasing the risk of oversights and unintentional errors. This is illustrated best with container five. The container entered the port with temperature breaks that had originated towards the end of the cold-store stage. After gate-in at approximately 14:30 on 3 March 2018, the temperatures of the container continued to rise for more than two days before the temperature decreased to below 2°C on 5 March 2018 at 22:30. The container was most likely left unplugged after it had been placed into the stacks due to a peak at the port.

6.4.6 Concern 6: ATD

There was a second, consistent rise in temperature in and around the Actual Time of Departure of the vessel. It was generally a smaller spike than those experienced at

gate-in and usually occurred during the loading-on-board-the-vessel stage. It is most likely caused by the length of time containers remain unplugged. The containers are unplugged from the stacks, transported to the vessel's quay side for loading, loaded on board and then only plugged into the vessel's power supply. This length of time as well as the containers' existing internal temperature, will determine the severity of the temperature spike. It should be noted that when containers are plugged into the stacks, an incremental decrease in temperature was recorded. This lowering and stabilization of the temperatures within the container resulted in the second spike, at ATD, being lower than that of the spike at gate-in. This trend was enhanced the longer the container stayed in the stacks, especially if it had pre-existing temperature breaks. Both containers ten and twelve spent almost identical, very short times in the port terminal of 01 day 16 hours 43 minutes and 01 day 16 hours 41 minutes respectively. Container twelve did not have any pre-existing temperature breaks and despite increasing incrementally in temperature during the loading process, remained within protocol range. Container ten, however, had pre-existing temperature breaks that did begin to decrease while in the port terminal, but not enough. Container ten did not spend enough time in the stacks to stabilize its temperatures and lower them back within protocol range. Thus, as soon as the container was unplugged from the stacks, the table grapes respiration rate began to increase again, in turn raising the temperatures and causing another temperature break.

7 Conclusions and Recommendations

7.1 Conclusion of study

The main driver of this research was the growing concern within the South African fruit industry of increasing losses, both financial and of the produce itself, due to temperature breaks in the export cold chains. Industry experts have attributed these increasing losses to a decline in fruit quality. As temperature is the most significant factor in the senescence of fruit, Company X prompted an investigative enquiry into their export cold chains of deciduous fruit from the Western Cape, South Africa to Europe and the United Kingdom. Thus, the aim of the research was to primarily identify if, where, with what frequency and for what duration temperature breaks occur along the export cold chain of apples, pears and table grapes starting from as close to the orchards or vines as possible until as close to retail shelf as possible, which is the point of contact with the end consumer. Due to restrictions and other practical limitations, the research commenced from the pack houses of the fruit and concluded at the first DC in the import country. The main purpose of the research was to map as complete as possible, the entire cold chain temperature profile of deciduous export fruit originating in the Western Cape of South Africa bound for the European and United Kingdom markets. For the purposes of this research and the analysis thereof, a cold chain temperature break was defined as, “every instance in which the temperature readings rise higher than 2°C or drop lower than -1.5°C (or -1°C in the case of pears) for longer than 90 minutes” (Fresh Produce Exporters’ Forum, 2016:105, Freiboth, Goedals-Gerber, Van Dyk & Dodd, 2013 & Goedhals-Gerber, Haasbroek, Freiboth & Van Dyk, 2015).

The literature review was conducted through secondary research. It examined all relevant aspects and placed the apple, pear and table grape export cold chains into context within South Africa. Further understanding was gained pertaining to the complexity of the export cold chains as well as the specific parties involved throughout the export process. Particular attention was paid to temperature regarding its function and effects on the fruit as well as within the cold chain. Furthermore, additional insights were gained into the effects and roles of packaging and horticulture to a lesser degree. Planning and primary qualitative research was conducted from November 2017. The qualitative research included observations on the farms, in pack houses, cold stores

and ports in South Africa as well as Europe. It was clear from the observations that despite some efforts made, specified protocols and procedures are not always perfectly adhered to. Further quantitative analysis was done through the temperature trials conducted from February to July 2018. Temperature monitoring devices, namely iButtons® and TempTales® were placed in and amongst the fruit and measured both the pulp and ambient temperatures every 30 minutes from the point of insertion at the pack houses to the first DC within the import country overseas. At the conclusion of the 24 temperature trials, 414 of the 504 initially inserted devices' data were retrieved. The 90 missing devices were either lost or unable to be read out. Despite this, there was still a total of 27 108 viable data points remaining.

The results of this study illustrate that there are no faultless cold chains and that there is always room for improvement with existing issues needing to be addressed. There are preventable temperature breaks occurring, which cause significant fluctuations within the temperature profiles of the fruit that should, ideally, be relatively constant. The fluctuations in turn, influence the speed of senescence, diminishing the fruit's quality and thus, negatively impact on shelf life, marketability and revenue generating potential.

Overall, the outcome of the study was to benefit both industry and academia. Concerning industry, the problem areas within their export cold chains, both known and unknown, were highlighted. This allowed Company X to internally investigate and rectify these issues, improving their business. Regarding academia, the almost complete mapped cold chains serve as confirmation and evidence of the detrimental and long-lasting effects of temperature breaks. Furthermore, new areas of further investigation have been suggested to complete the entire knowledge base of deciduous fruit cold chains.

7.1.1 Research questions one: Do temperature breaks occur along the export cold chain of pome fruit and table grapes from the Western Cape to Europe and the United Kingdom?

Yes, temperature breaks do occur along the export cold chain of pome fruit and table grapes from the Western Cape to Europe and the United Kingdom.

7.1.2 Research questions two and three: Where and with what frequency do the temperature breaks occur? How long do the temperature breaks last for?

Tables 5.6 through 5.14 in chapter five summarise and elaborate on the location number of pulp and ambient, hot and cold, temperature breaks experienced in three ways. Firstly, collectively per fruit kind per cold chain stage. Secondly, the number of container breaks experienced per container and lastly, the number of device breaks experienced per container. In chapter six, Figures 6.1 through 6.6 illustrate the duration of the temperature breaks as well as the number of temperature breaks per stage for all three fruit kinds.

There are three main areas during the South African leg of the cold chain where temperature violations are prevalent in all three fruit kinds. Firstly, in the pack-house and cold-store stages. Secondly, in and around the gate-in date and time. Thirdly, just prior to ATD, usually around when the container is loaded onto the vessel. The majority of temperature breaks recorded across all the trials were at the beginning of the cold chains during the pack-house and cold-store stages.

The table grapes cold chain did not experience any temperature breaks during the UK Transport leg. However, there were three main areas during The Netherlands leg of the pome fruit cold chains where temperature violations were prevalent. The first area was after the ATA of the vessel at the port of import. The second occurred during the barge stage of the pome fruit cold chains, but was not applicable to all the containers as only four of the ten pome fruit containers were barged. The third was noted at the end of the cold chain during the unloading of the container where the container doors were opened and devices removed. Overall, the pear trial containers had a tendency of experiencing the temperature breaks for a little bit longer than the apples did.

7.1.3 Research questions four and five: If a temperature break was experienced, did containers with more temperature breaks have worse quality reports than those with fewer temperature breaks? What was the effect of the temperature breaks on the physical fruit quality?

Regarding the pome fruit trials, the quality reports received were done based on an in-house inspection. The apple trials had seventeen reports and the pear trials had thirty six reports respectively. Apple container nine experienced the most temperature breaks both on a device and container level. It was also the only container to have a

major quality control issue of decay. Figure 5.7 depicts the quality control status per apple container and Figure 5.8 depicts the minor quality control issues per apple container. Pear containers five and six experienced the highest numbers of both device and container temperature breaks. Both containers suffered from major quality control issues of mould growth along with minor quality control issues of injuries, blemishes, sun blush and yellowing. Figure 5.10 depicts the control status per pear trial and Figure 5.11 depicts the minor quality control issues per pear container.

Regarding the table grapes trials, twenty two quality reports were received. The reports were done by an outside company. The first half of the table grape trials tended to have more temperature breaks than the second half of the trials, however, the quality reports became increasingly worse. This is partially attributed to the drought and the fact that the first fruits harvested had the best quality. As the season progressed and started to draw to a close, the quality of table grapes harvested decreased.

It is difficult to view the quality reports and their remarks as completely unbiased as the pome fruits were done in-house and the table grapes reports were done by the receiver. The in-house reports would want to reflect the best possible outcome and would see the glass as half full in order to ask a premium for the imported products. The receiver reports would want to reflect the worst possible outcome and see the glass as half empty in order to pay less or receive a discount for the products received.

7.1.4 Research question six: Are there any current measures in place attempting to inhibit temperature breaks from occurring and do they impact on fruit quality?

Through the observations done during the temperature trials, it was noted that the current South African facilities do have temperature break inhibiting amenities, such as airlocks on loading bays and shaded outside storage areas, available and at their disposal. The facilities and their amenities are just not being used efficiently nor effectively.

In addition, it is also clear that role players, especially in the initial stages of the cold chain, do not fully understand the cold chain or their influence on it. From farm, pack house and cold store levels, the labourers are predominantly focussed on speed and throughput. This is due to a combination of factors including pressure placed on the farmers to harvest mass volumes in order to push their product to market first and

receive a higher profit margin. Incentive programmes are often established for labourers based on throughput volumes with little regard for the end quality. Rushing the produce through the cold chain processes to reach the maximum revenue possible is actually counterintuitive. The quality diminishing effects of the temperature breaks experienced as a result of the initial rush lower the revenue generating potential of the fruit. Furthermore, the excess heat and moisture levels as a result of the warmer fruits' increased respiration rates due to the temperature breaks experienced, creates the perfect environment for pathogens to develop.

7.1.5 Respiration and quality

Fruits differ in many respects, but one of the most important aspects is its ripening category. The ripening category of the fruits, namely, climacteric and non-climacteric, in conjunction with temperature, rate of respiration and ethylene synthesis can greatly influence the life span and quality of the fruits upon arrival in the country of import. In essence, fruits are living objects that breathe, with a fixed amount of energy reserves and a finite lifespan.

Climacteric fruits, such as apples and pears, can continue to ripen once harvested, while non-climacteric fruits such as table grapes, cannot and immediately begin to decay. As a result, non-climacteric fruits have a shorter shelf life than climacteric fruits. Thus, table grapes have the shortest shelf life, followed by pears and then apples.

In order to respire, the fruits convert some of its limited energy reserves, carbohydrates usually in the forms of starches or sugars and oxygen, into energy. This energy is mostly in the form of heat, as well as water and carbon dioxide. As the respiration process continues, more limited carbohydrates are used for energy creation, which diminishes compounds that affect the fruit's flavour, sweetness, turgor and nutritional value. This, in turn, has a detrimental effect on the fruit's overall quality and shelf life. In addition, temperature has a substantial effect on the rate of respiration. An increase in temperature has an accelerating effect on the rate of respiration in fruits, which hastens the diminishing of the fruit's shelf life as well as quality. A decrease in temperature can therefore, slow the respiration rate of the fruits and in turn increase their shelf life. Consequently, temperature fluctuations can increase or decrease the rate of respiration of the fruit, essentially, waking up or putting the fruit to sleep, but it still depletes its energy reserves.

When the temperature increases from cold to hot, there is energy absorption on molecular level. Thus, in a warmer atmosphere, the cold fruit begins to lose its coldness in order to equalize the temperature. The fruit itself becomes warmer and starts to wake up. The increase in its respiration rate generates additional heat and uses more of fruit's limited energy reserves, shortening its shelf life and reducing quality. The temperature fluctuations speed up and slow down this process, but the fruits only have a fixed amount of energy reserves and once depleted the fruit is no longer fit for consumption. This illustrates the cumulative nature of temperature breaks on the fruit quality. Furthermore, the additional heat generated by the increased respiration rate, warms further fruits and makes it even harder for the fruit as well as the reefer container to dissipate the heat gained and lower the respiration rate once again to put the fruit to sleep.

The heat gained by the bottom cartons of the pome fruit trials in conjunction with the increased respiration rate is largely the reason behind the increase and sustained warmer overall temperatures seen from the point of gate-in for the remainder of the journey.

Due to the impact of the sustained drought on the fruit trees and vines and its implications on the initial fruit quality produced, the fruits did not start at their absolute maximum peak quality. This made the effects of the temperature breaks all that much more severe especially in most the temperature sensitive commodity, table grapes.

7.2 Recommendations

Further education on the role of temperature within the cold chain and the detrimental effects of temperature breaks as well as other good cold chain practices should be taught to farmers, labourers and workers. This will allow for ownership of actions and give an understanding of how their actions can have repercussions much further down the cold chain. Addressing the lack of knowledge and understanding could help to improve adherence to good cold chain practices by showing that if done correctly, the fruit will be of a higher quality and ultimately fetch higher prices thus, generating more revenue. The adaption of the 'Good Cold Chain Practice Guide' for table grapes by Haasbroek (2013) into a guide for pome fruits is recommended. Additional education should also be given regularly regarding the environmental impacts of the industry to

all role players and stakeholders to stimulate environmental awareness and to remain up to date with possible improvements.

Moreover, possible industry incentives could be given by the port to encourage farmers or exporters to get their containers to port earlier to eliminate the bottle necks and congestion prior to loading of the vessel. In addition, the setting up of a slot adherence system at the port for container deliveries, such as those seen at distribution centres, is recommended to further eliminate bottle necks and congestion and increase the ease of delivery. Finally, investigating the possibility of independent quality control reports to eliminate any possible bias and to attain a comprehensive and detailed quality inspection.

Concerning specific recommendations for issues highlighted in this research, there are two recommendations. Firstly, corrections of the water bath temperature in the pome fruit pack houses must be addressed. Thermometers should be placed into the water at regular intervals along the water bath pathway in the pack houses to keep track of changes in the water temperature. There is currently no equipment in place indicating the water temperature of the water bath. Secondly, a cost benefit analysis into the upgrading of all non-temperature-controlled airlocks to temperature-controlled airlocks should be investigated. Temperature controlled airlocks are more expensive, but have been shown to have lower temperature variations (Henning, 2019:41). A further option for a possible cost benefit analysis is to place the entire cold store underroof. This would eliminate the issue of the heat gained by the bottom cartons due to the sun warmed concrete. In addition, having the entire facility temperature controlled would further lower the risk of temperature fluctuations and thus, quality diminishing temperature breaks, from occurring all together.

Attaining the answers to the above-mentioned research questions through this research brought to light possible weak links and problem areas within the export cold chain of apples, pears and table grapes. This research was the first step in ascertaining where and why these issues occur. Through the improvement, minimization and ultimately, total eradication of these temperature breaks, an improvement in the overall efficiency and effectiveness of the entire cold chain can be realised.

7.3 Future research

Pertaining to this research specifically, investigating the possibility of mapping the final stages of the three cold chains from the first DC in the country of import through to the retailer and finally to the end consumer would be greatly beneficial. Despite this being in the initial scope of this research, the unwillingness of retailers to cooperate in such a trial as well as the difficulty of not being in close proximity to the retailers to retrieve the devices could not be overcome. The trial per fruit kind that were sent to retailers were lost in their entirety. A collaborative effort with someone in the import country is suggested. Furthermore, the possibility of placing additional ethylene monitors in the probed cartons could assist in determining the actual shelf life of the produce versus the shelf life printed on the labels. This could help give a true indication of the relationship between temperature, quality and shelf life.

Furthermore, the environmental impact and energy consumption in cold chains is something that is of great concern. Food transport refrigeration uses 15% of global fossil fuel energy (Adekomaya, Jamiru, Sadiku, Huan, 2016). Bearing in mind that 40% of all foods require refrigeration (Adekomaya *et al*, 2016), proper cold chain management not only plays a critical role in the preservation of food stuffs, but also has a considerable impact on the environment. With an ever-increasing global population demanding more and more food with ever fewer resources, the responsible, sustainable and energy efficient management of food cold chains is now imperative. With the growing concern among consumers and industry alike regarding their carbon footprints and environmental impacts, in direct conflict with catering for new, year round demand of fresh fruits, industry is at a stalemate. Through resolving and improving upon the current weak links in the export cold chain and minimizing things such as food waste, a cycle of continuous improvement can be implemented. This will not only enable businesses to cater to more markets, but to deliver a better quality end product to customers, while being more environmentally conscious through the elimination of wasteful energy consumption practices and reducing food wastage through lower rejection rates.

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9 Appendix

9.1 Appendix A: Apple trials *Statistica* time series line graphs

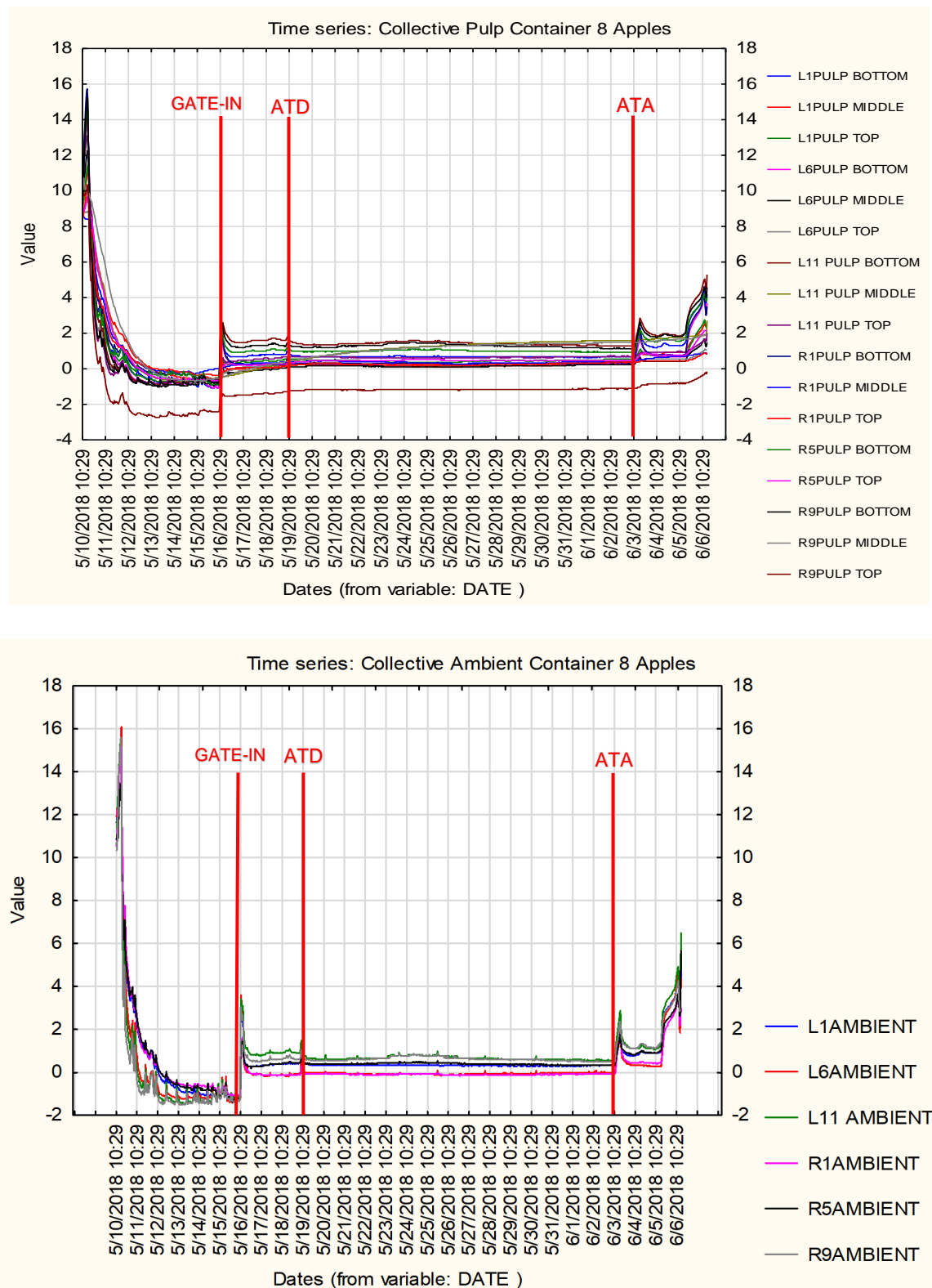


Figure 9.1 Time series line graphs of pulp & ambient temperature profiles of apples container eight

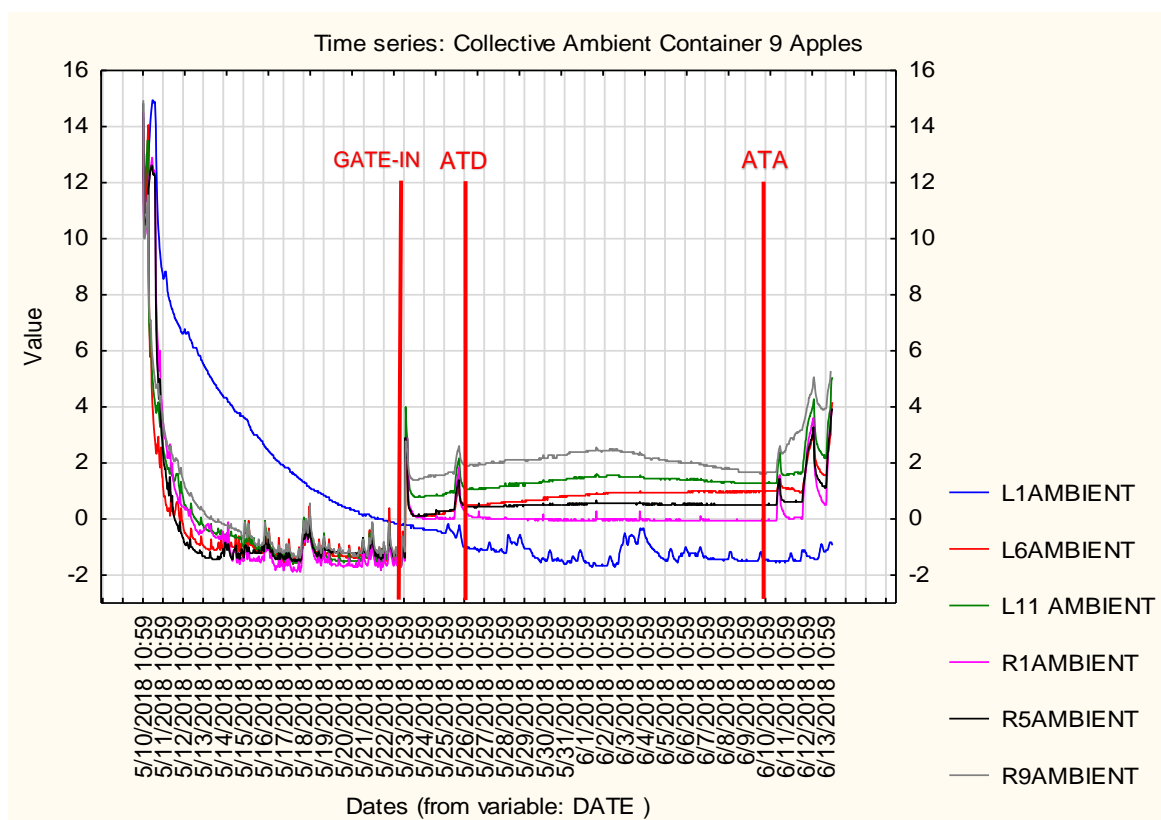
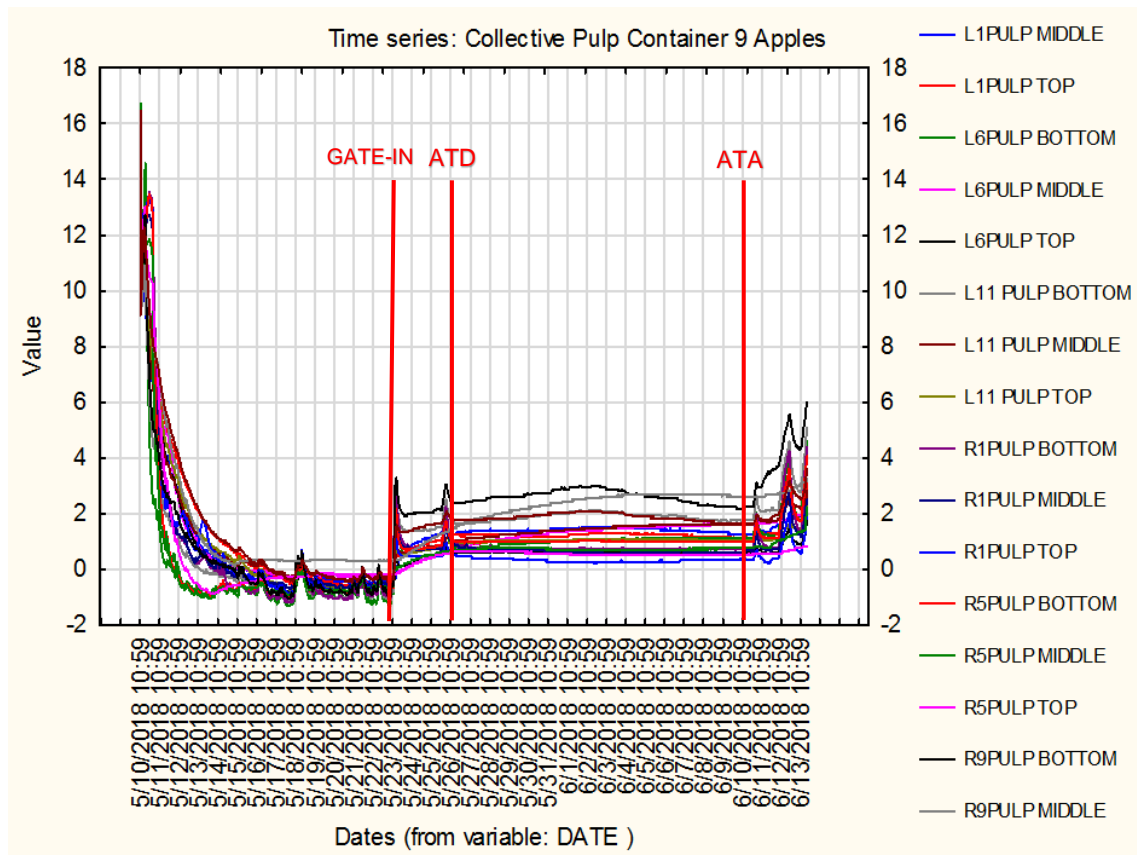


Figure 9.2 Time series line graphs of pulp & ambient temperature profiles of apples container nine

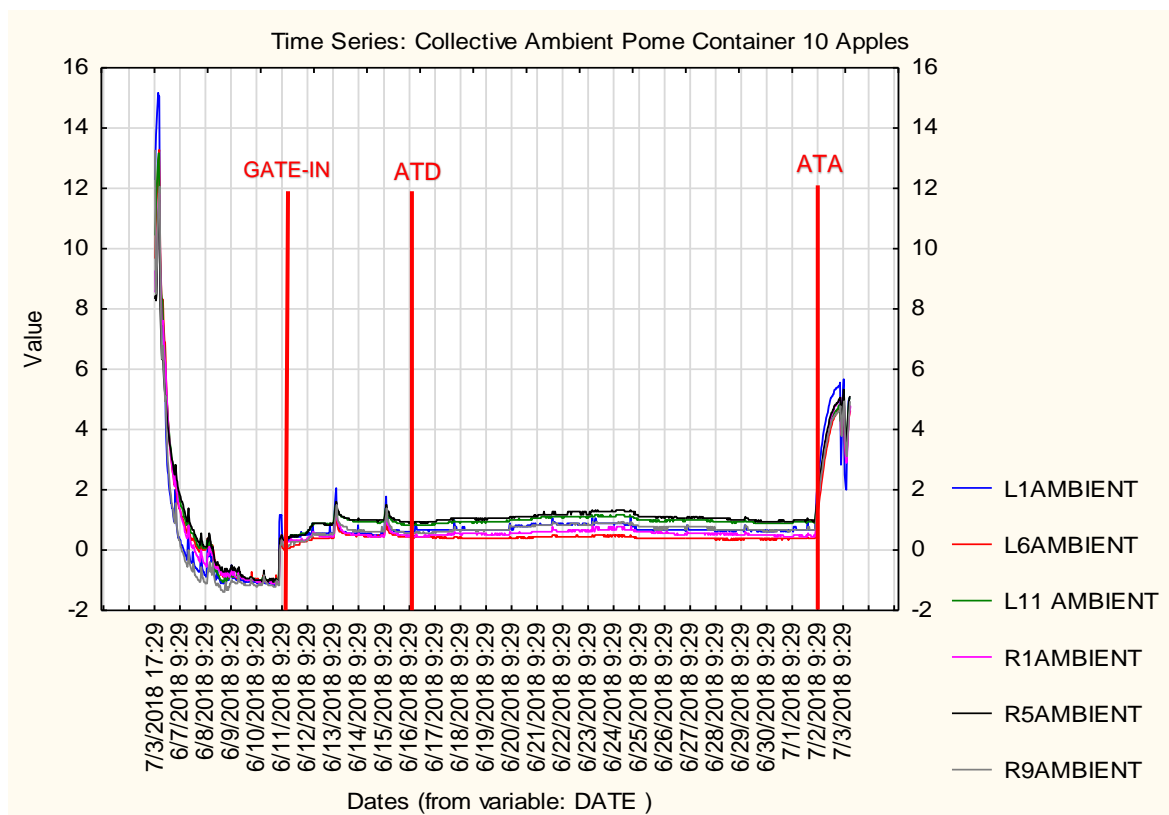
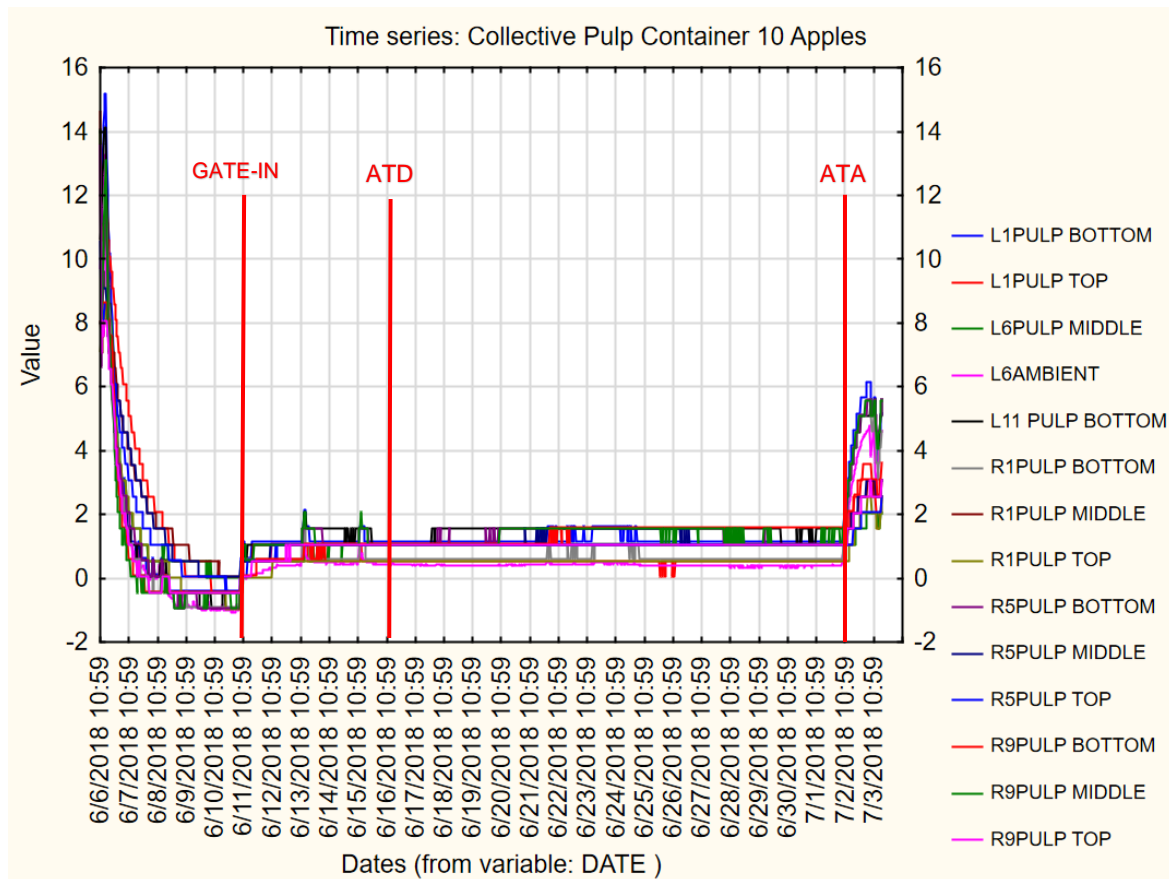


Figure 9.3 Time series line graphs of pulp & ambient temperature profiles of apples container ten

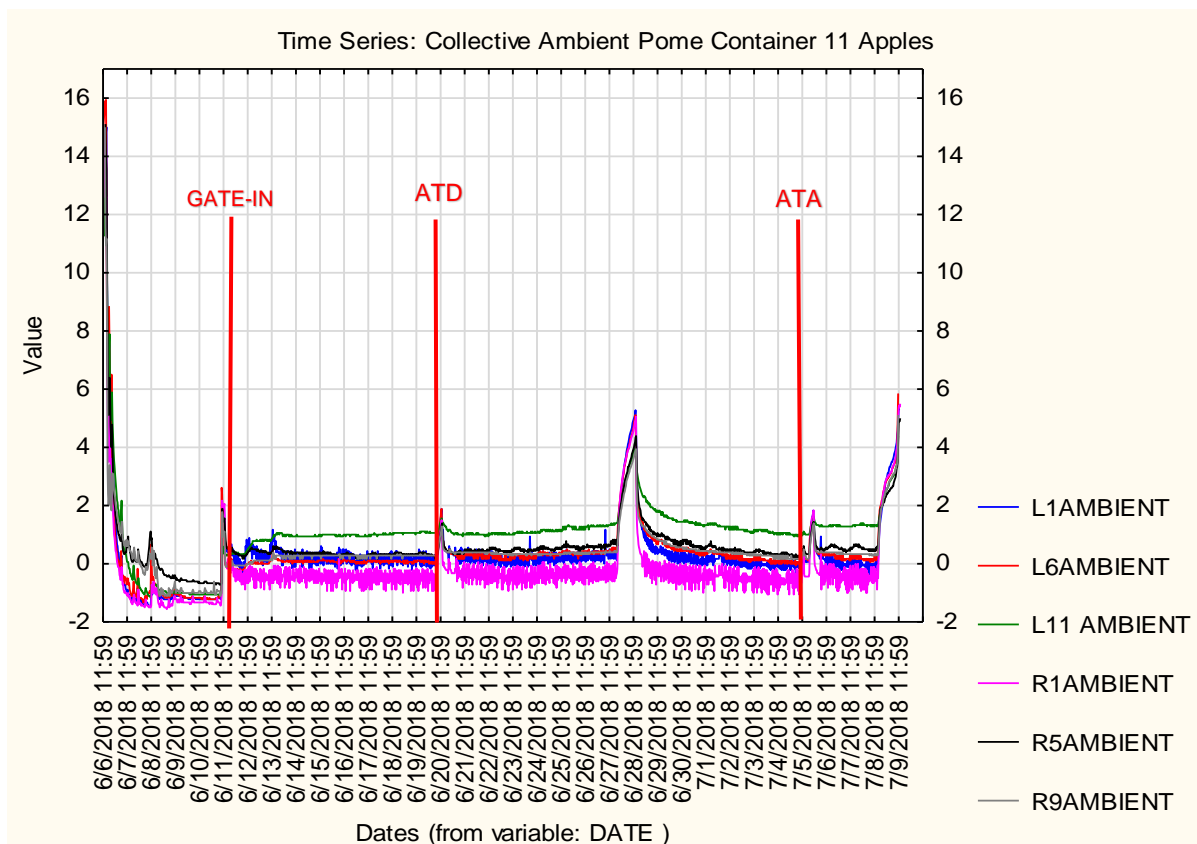
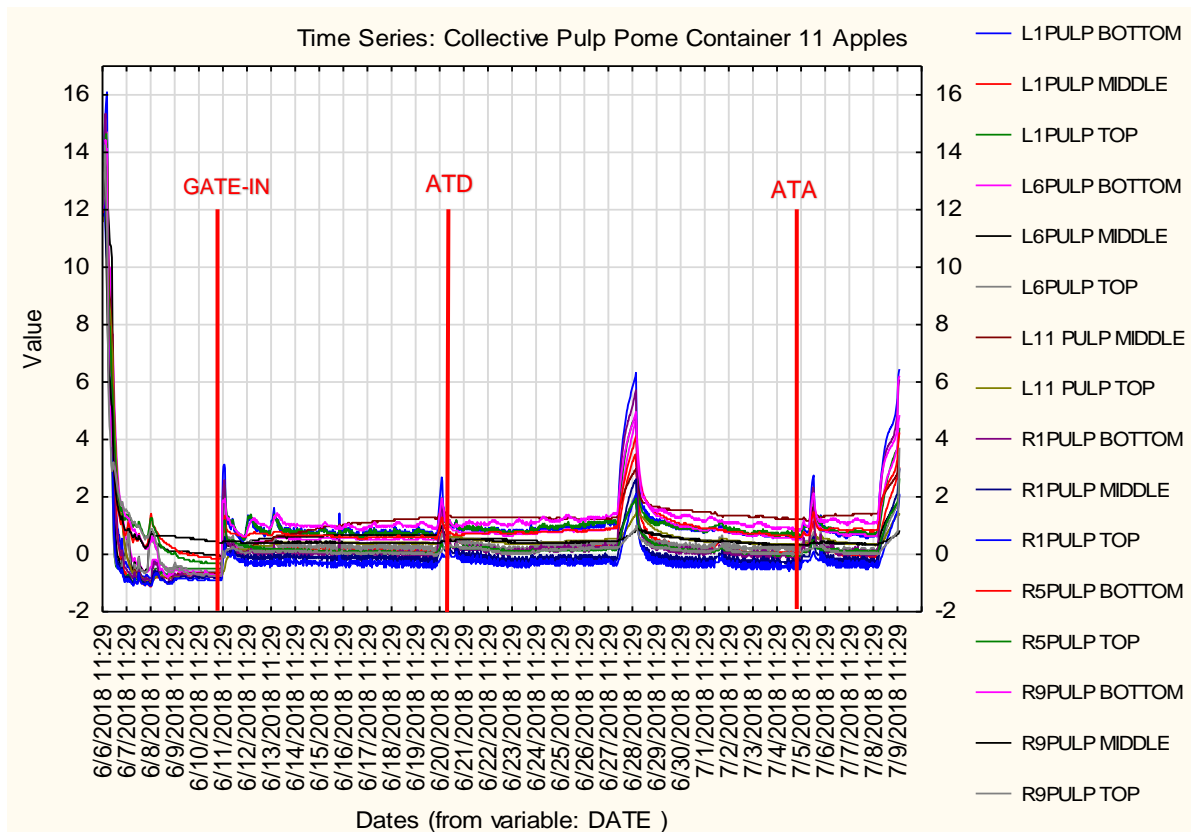


Figure 9.4 Time series line graphs of pulp & ambient temperature profiles of apples container eleven

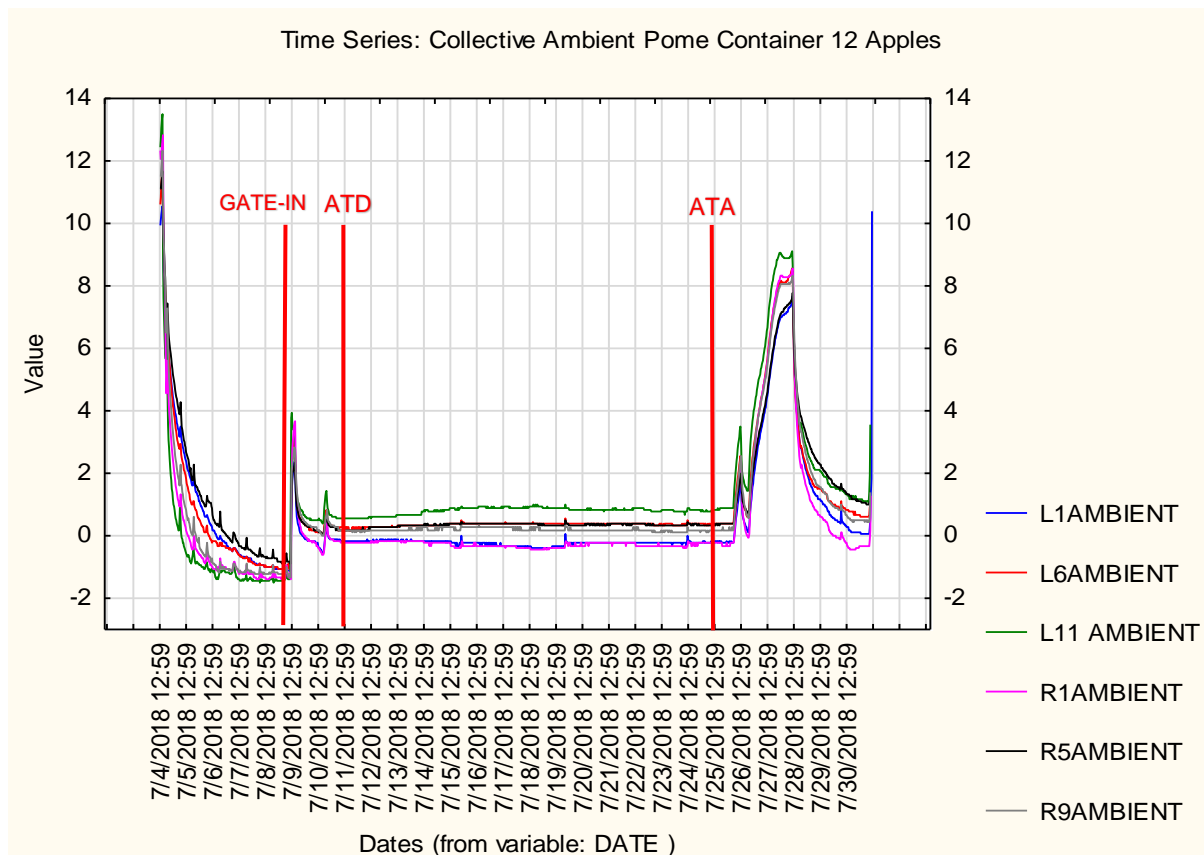
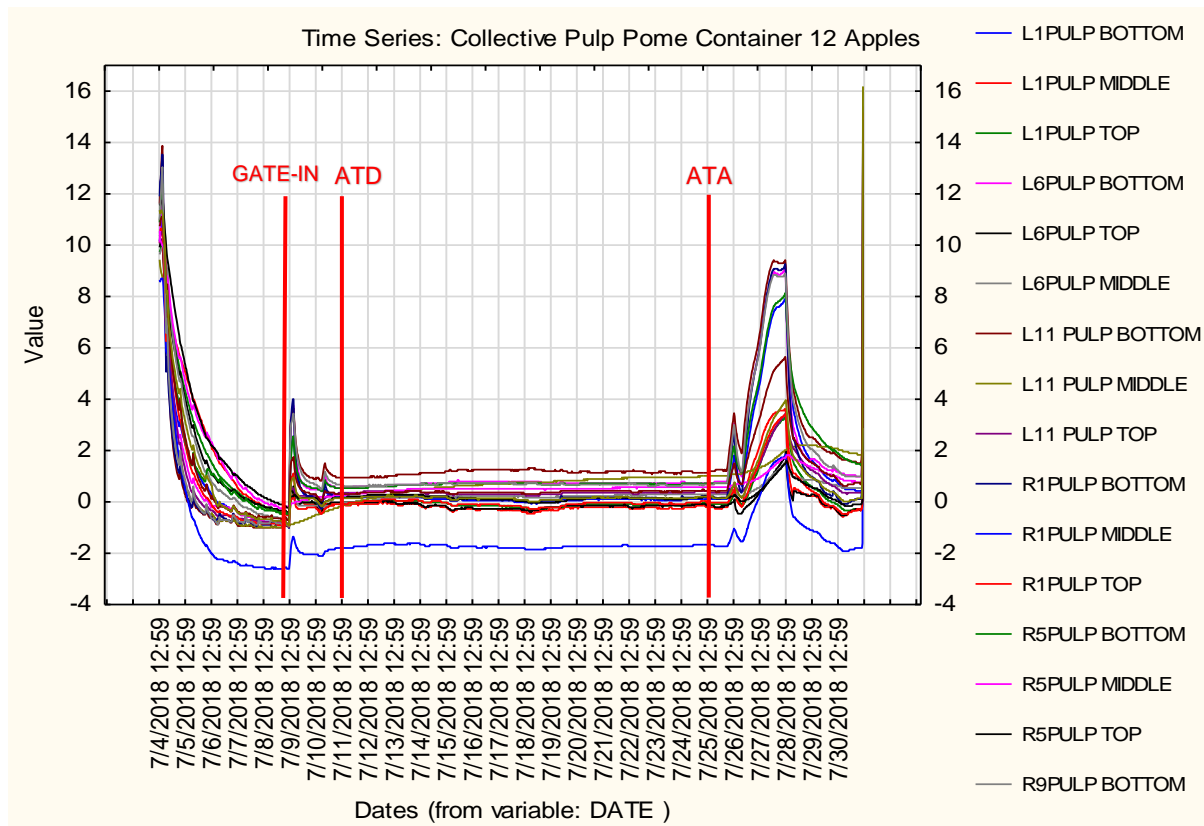


Figure 9.5 Time series line graphs of pulp & ambient temperature profiles of apples container twelve

9.2 Appendix B: Pear trials *Statistica* time series line graphs

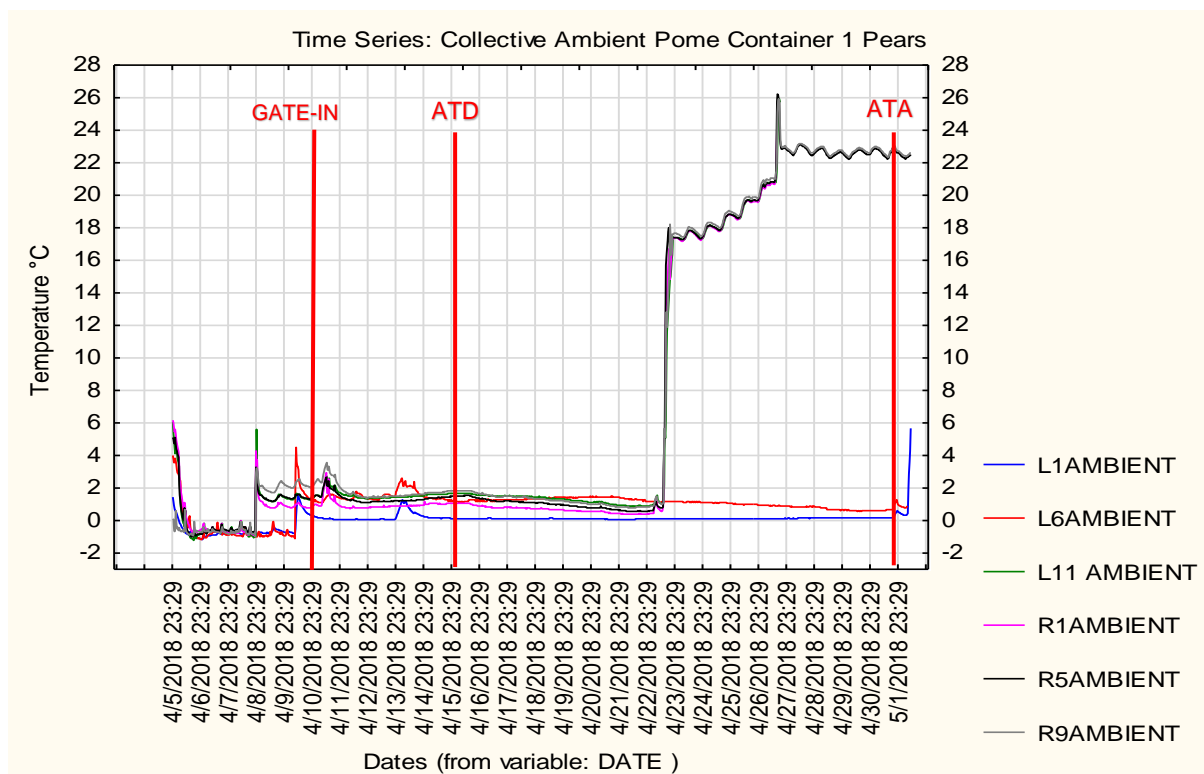
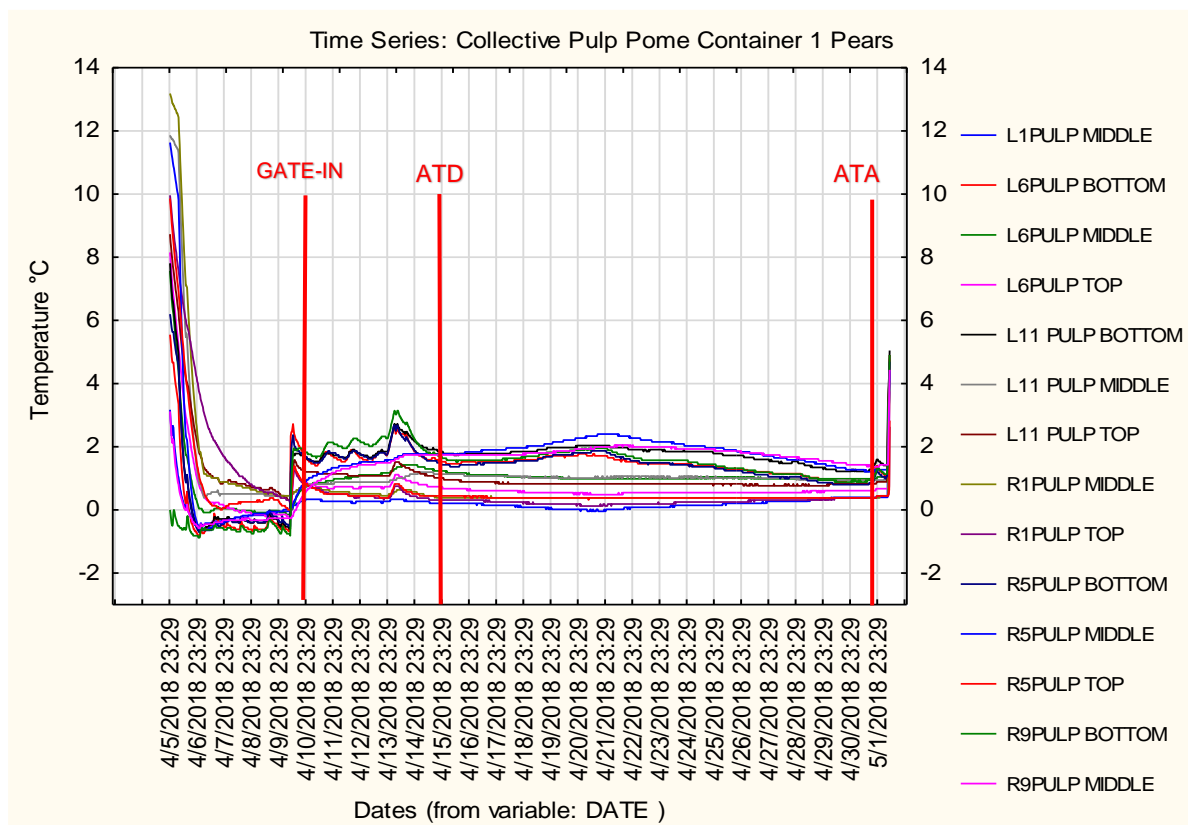


Figure 9.6 Time series line graphs of pulp & ambient temperature profiles of pears container one

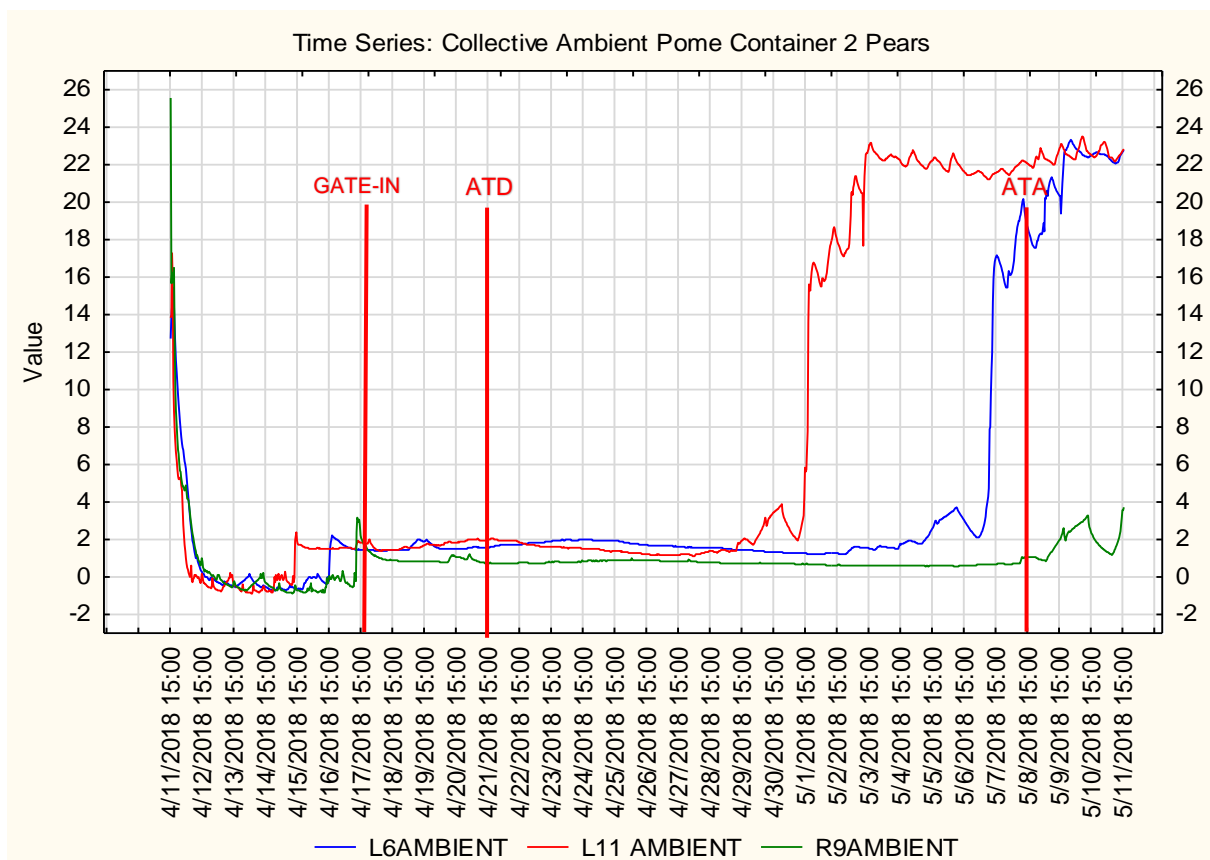
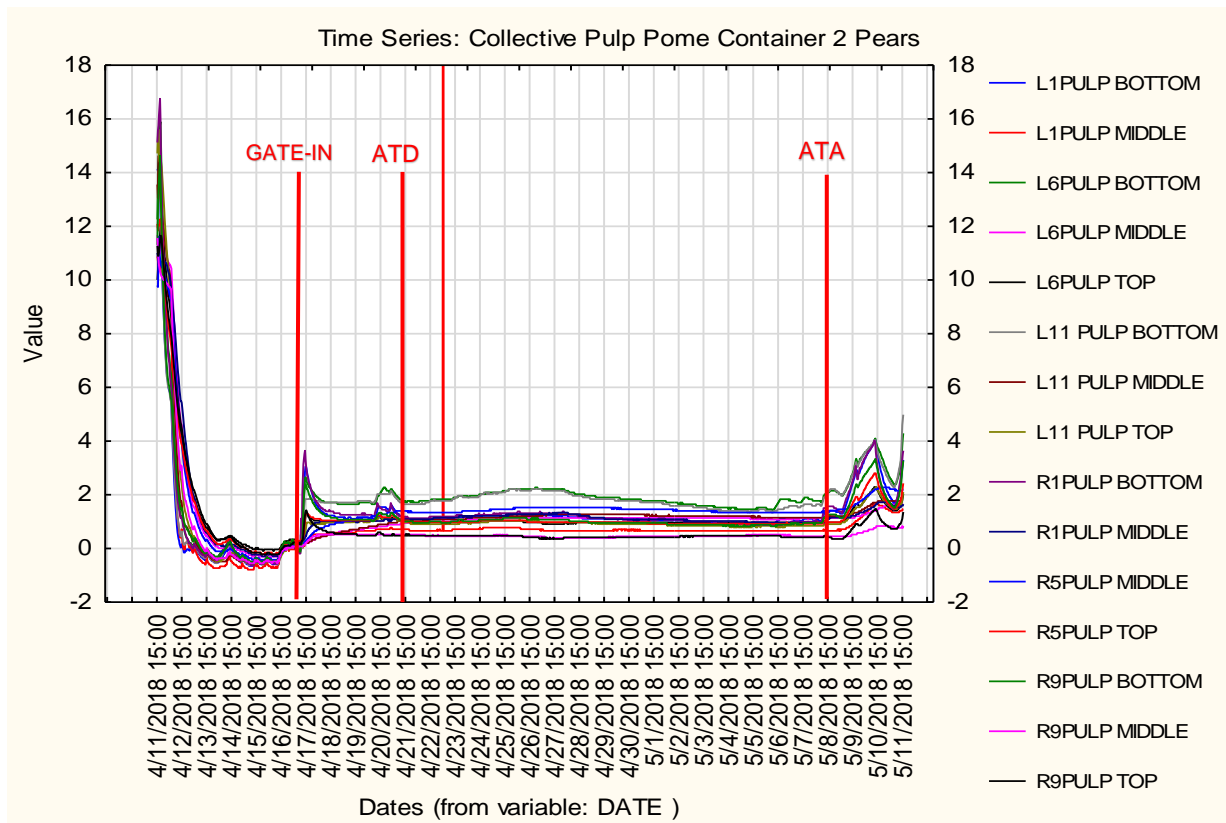


Figure 9.7 Time series line graphs of pulp & ambient temperature profiles of pears container two

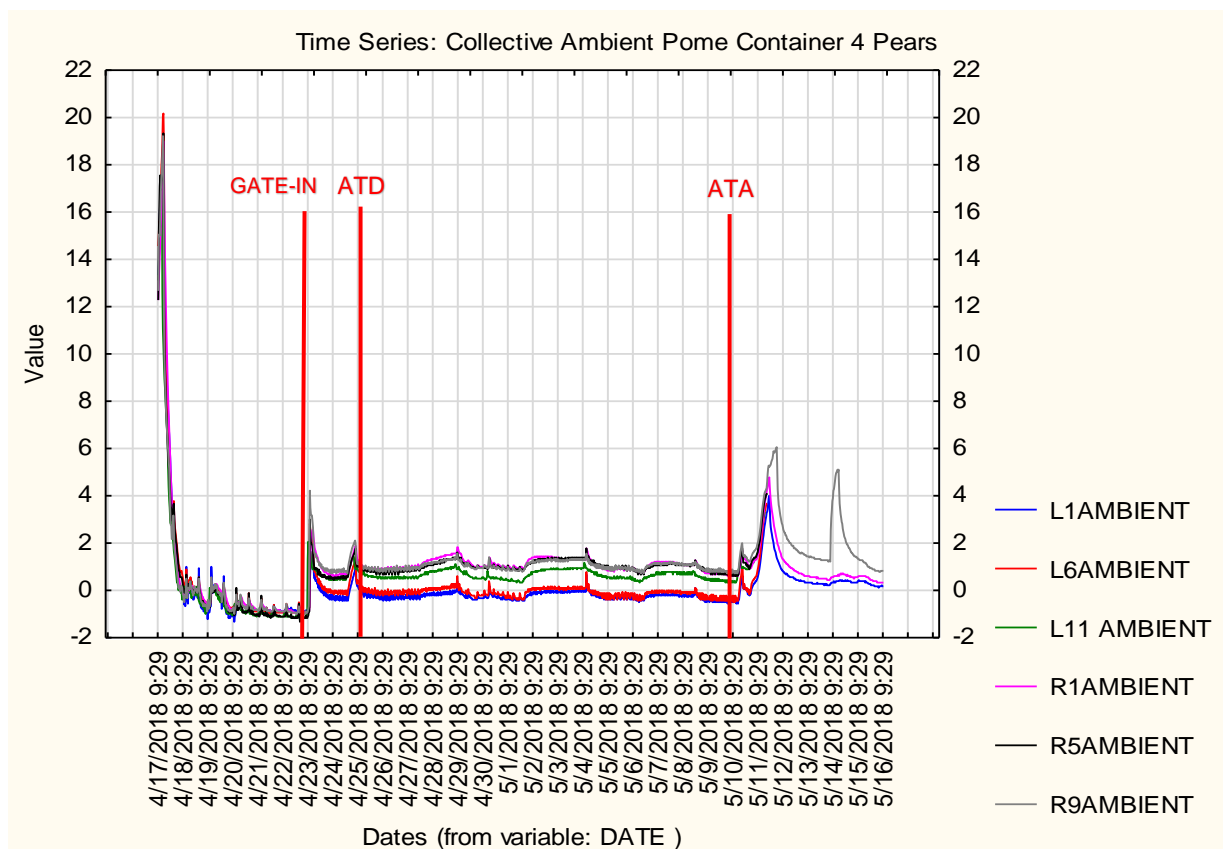
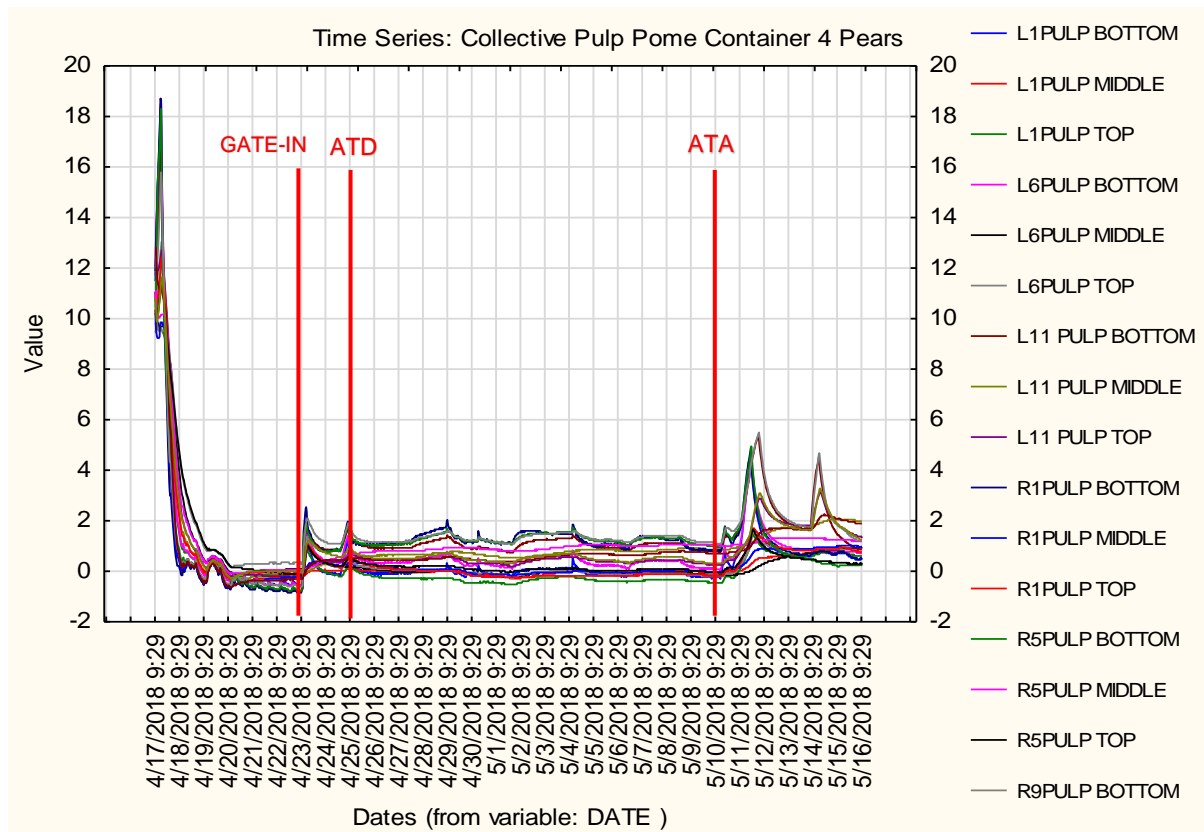


Figure 9.8 Time series line graphs of pulp & ambient temperature profiles of pears container four

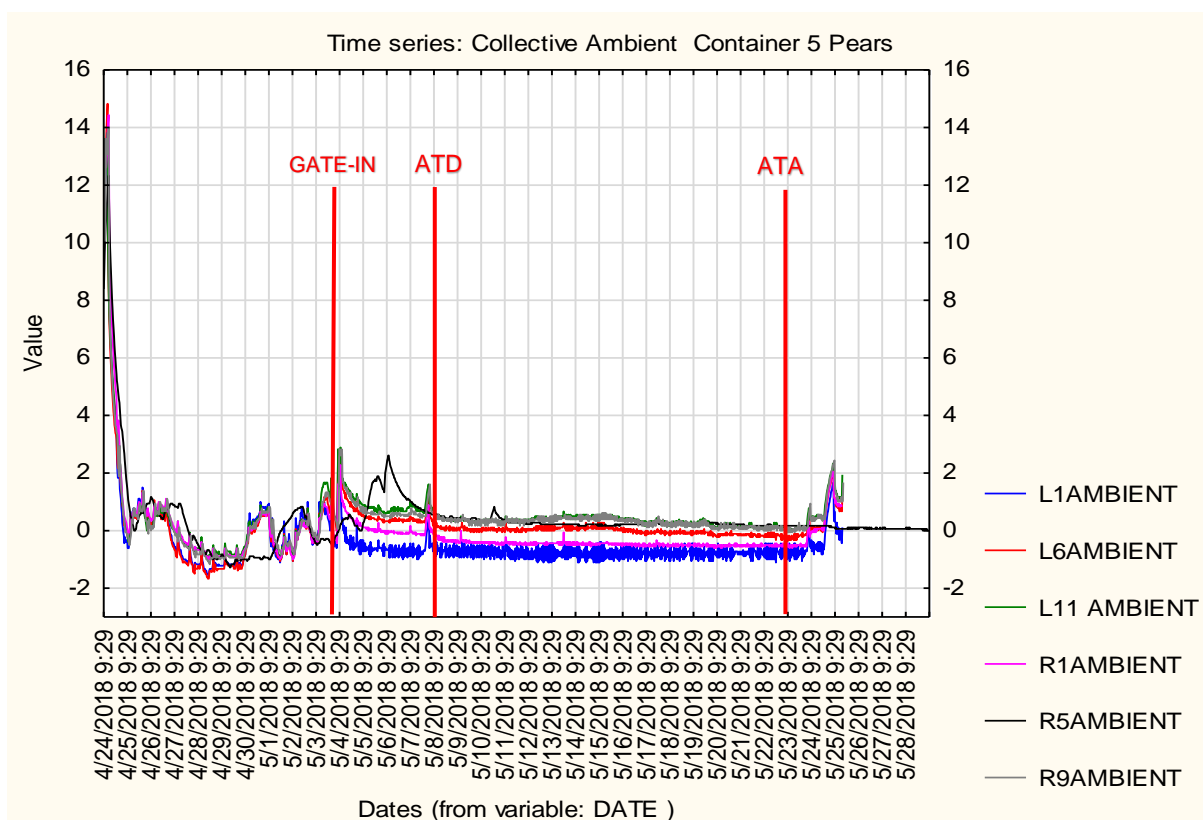
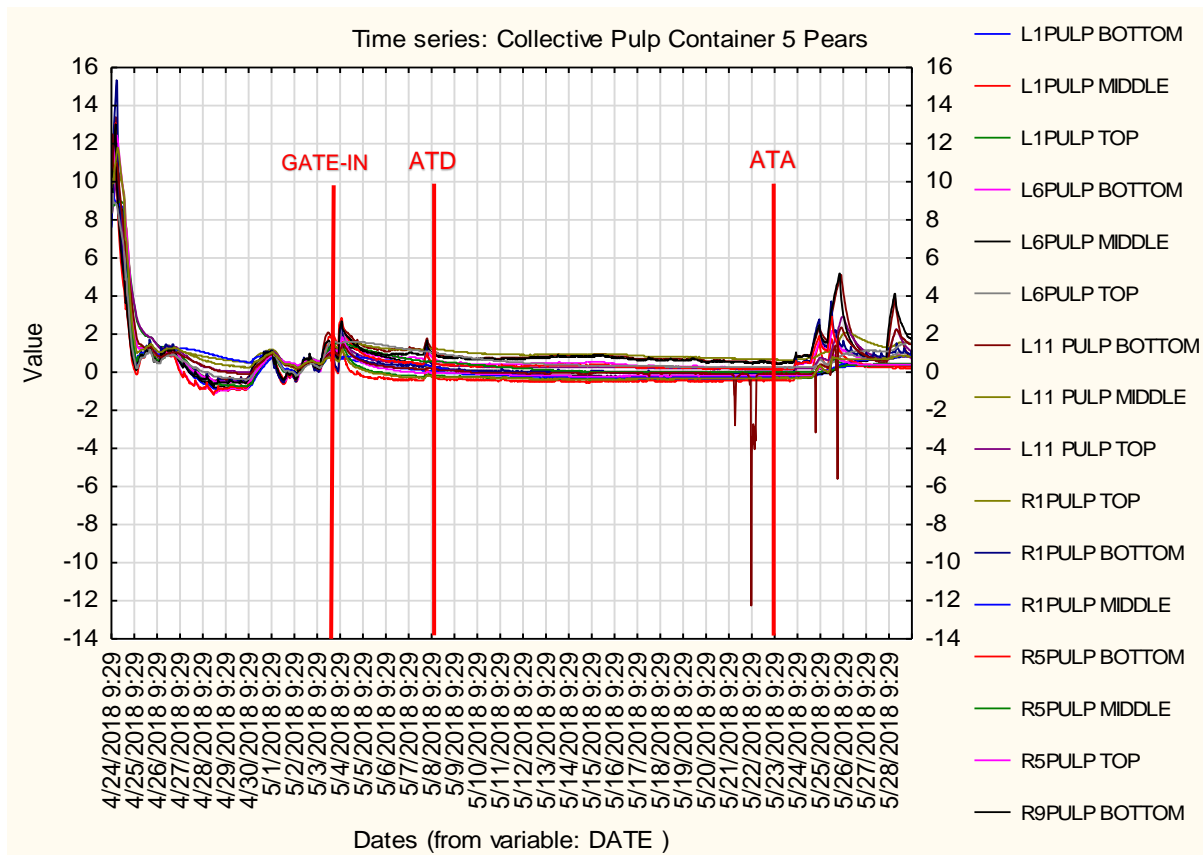


Figure 9.9 Time series line graphs of pulp & ambient temperature profiles of pears container five

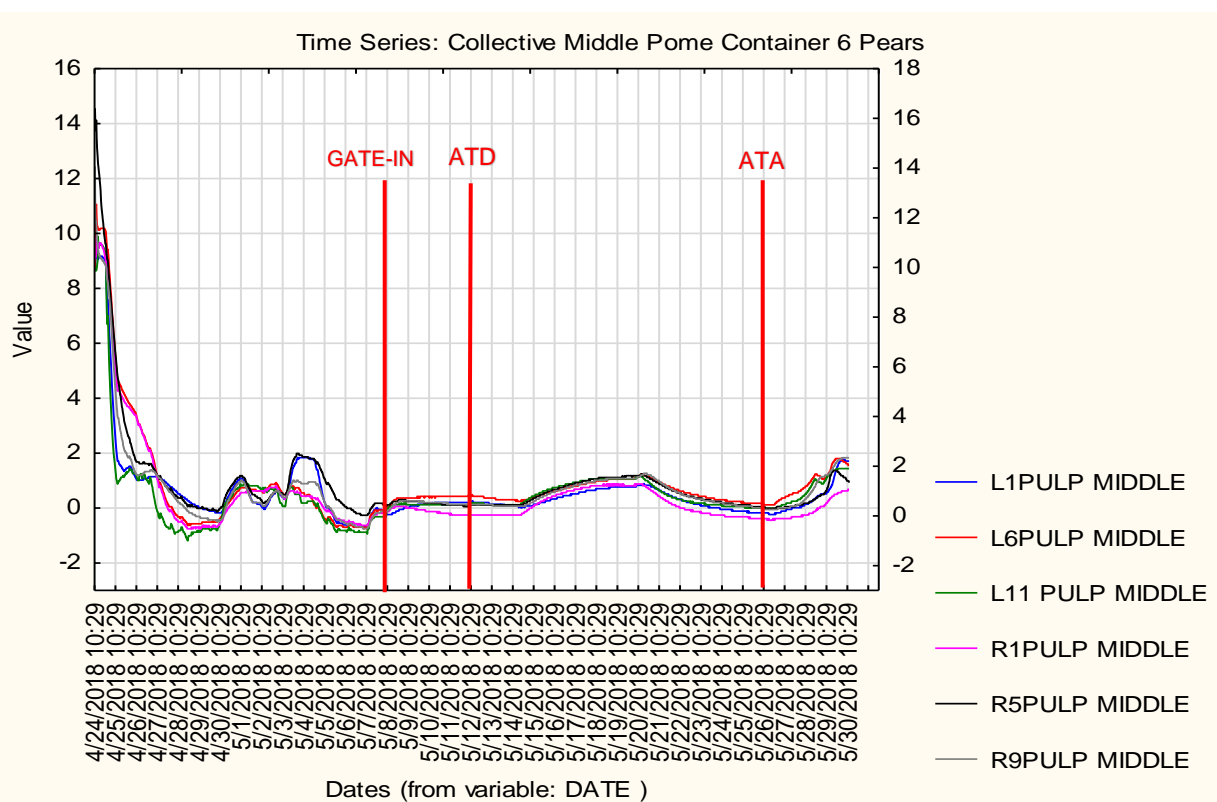
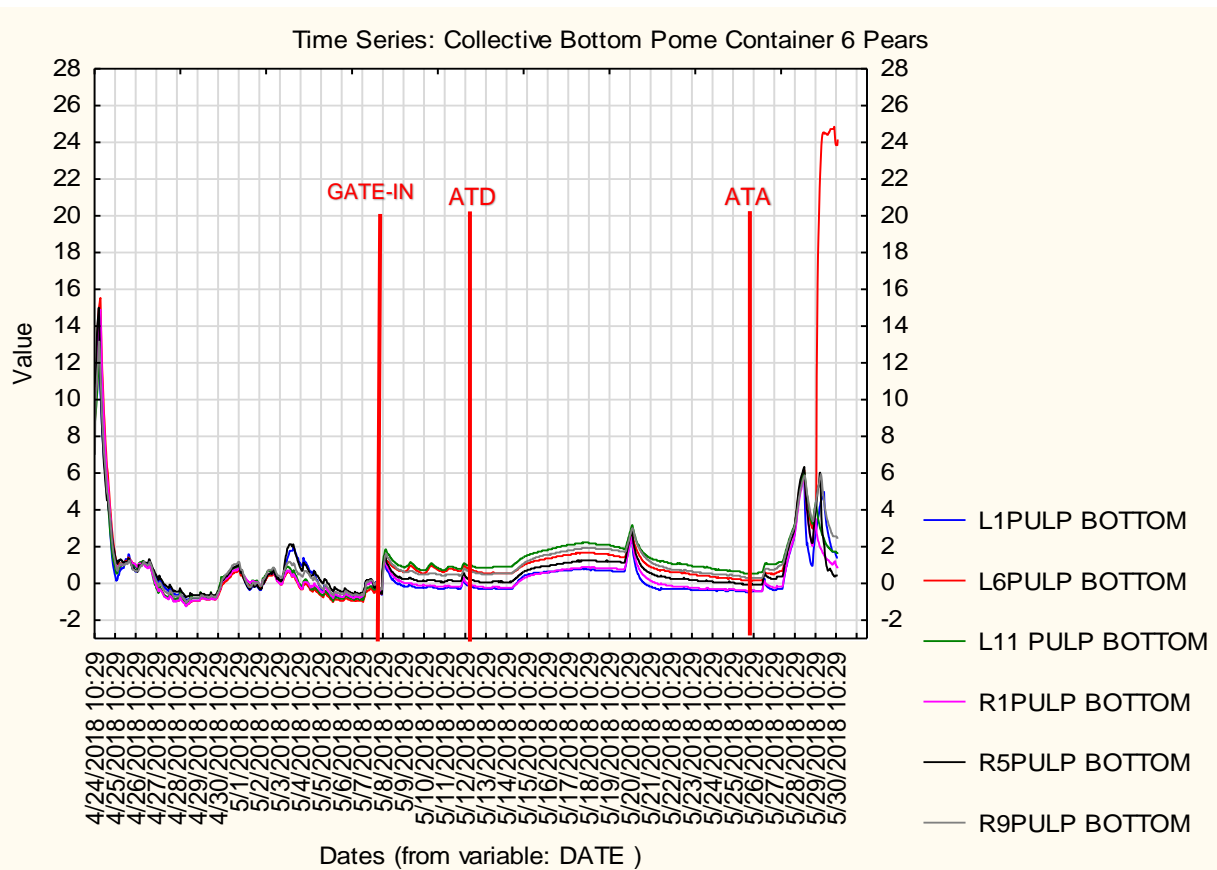


Figure 9.10 Time series line graphs of pulp & ambient temperature profiles of pears container six

9.3 Appendix C: Table grapes *Statistica* time series line graphs

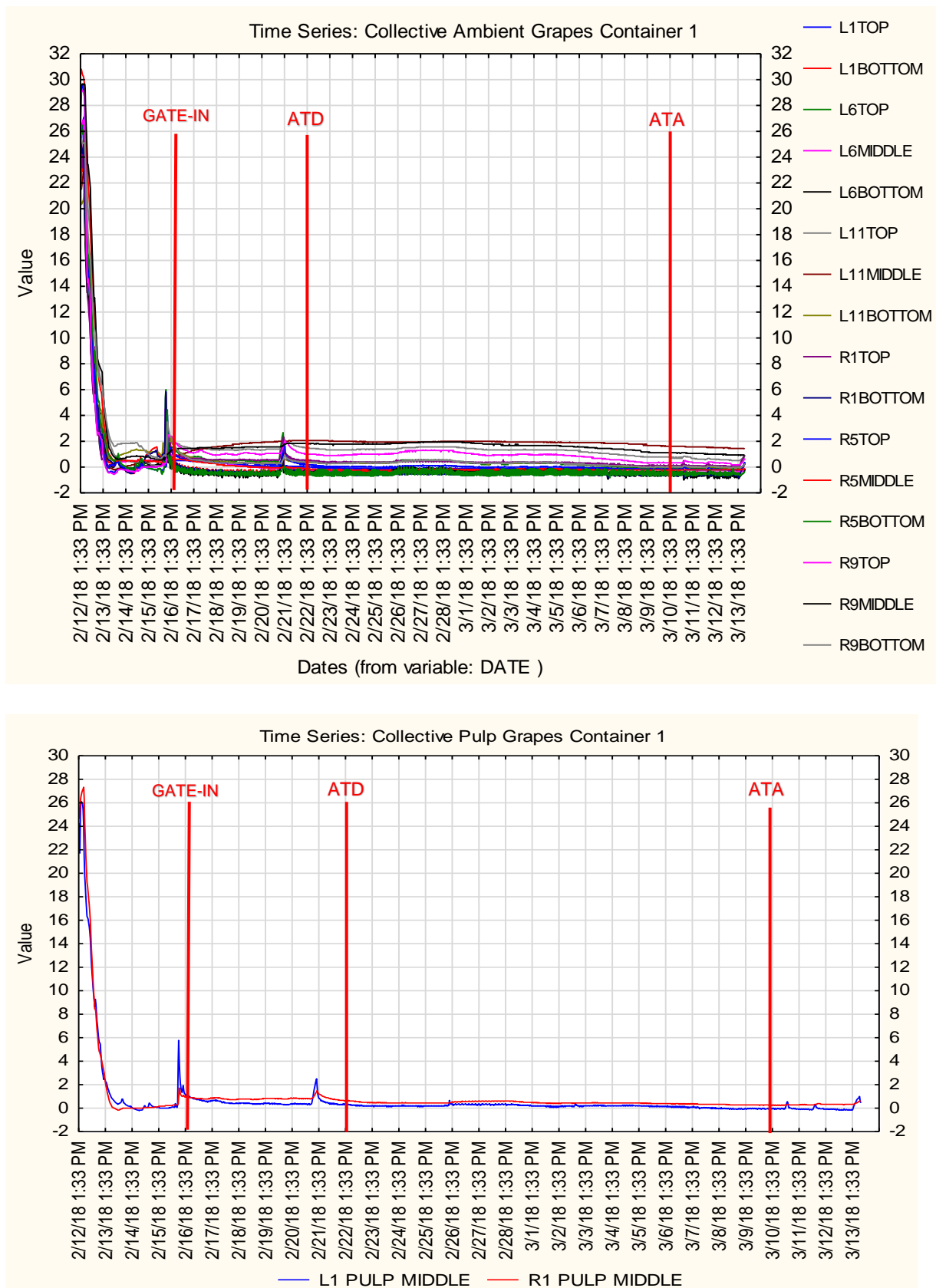


Figure 9.11 Time series line graphs of pulp & ambient temperature profiles of grapes container one

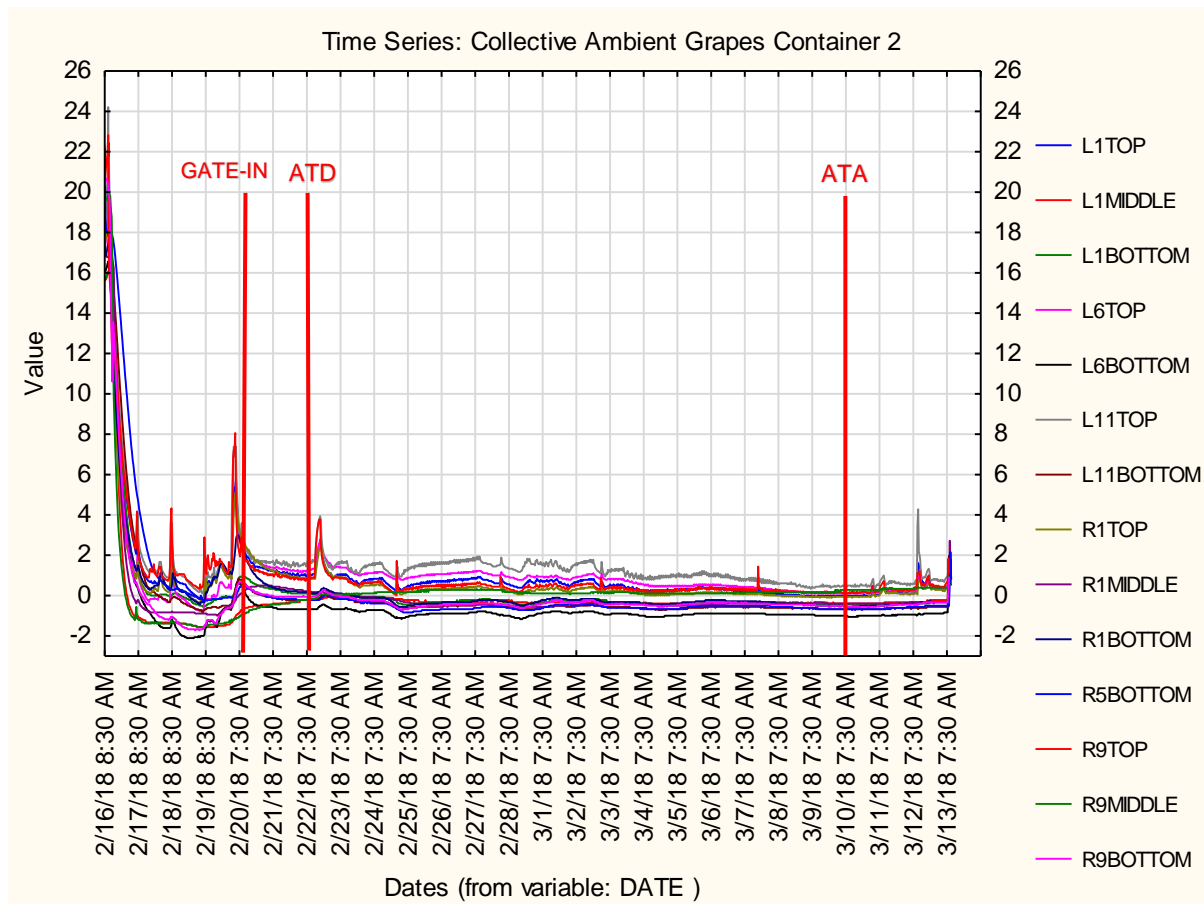


Figure 9.12 Time series line graph of ambient temperature profile of grapes container two

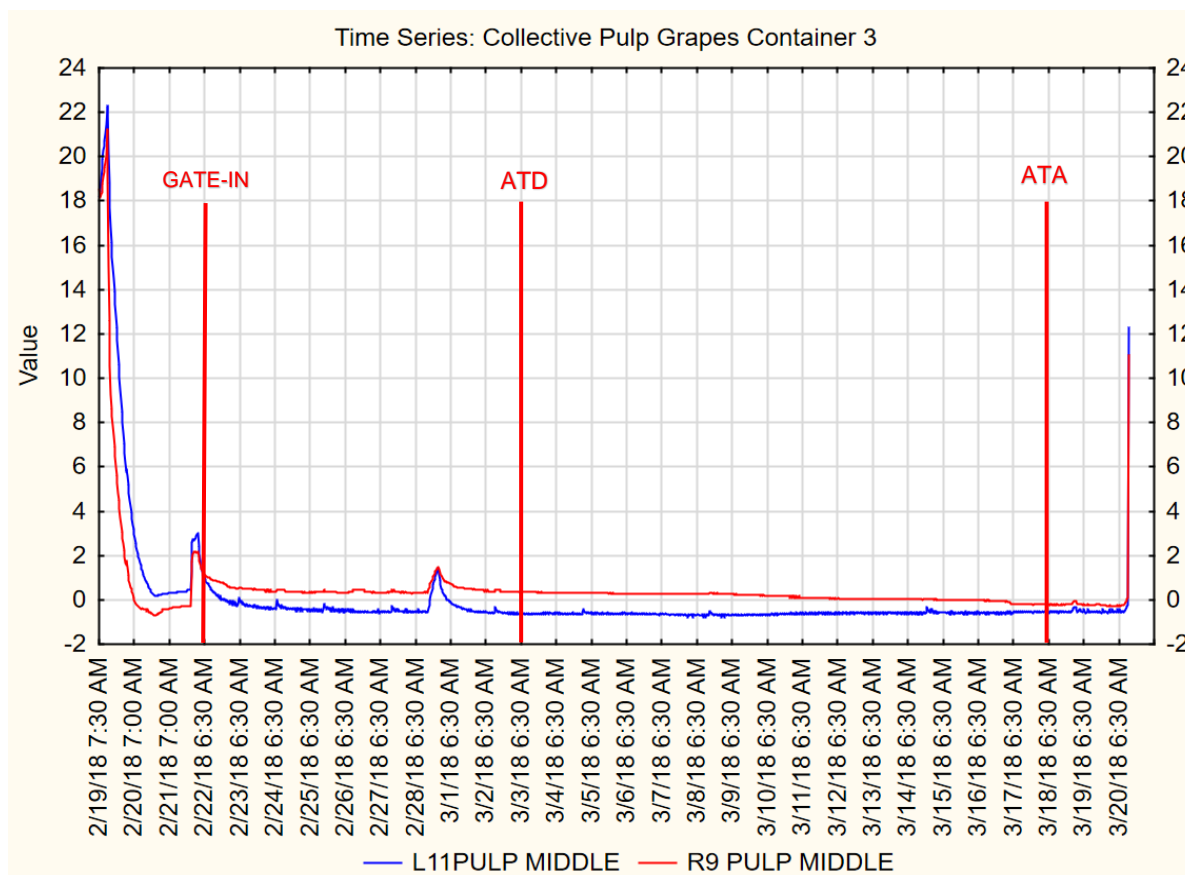
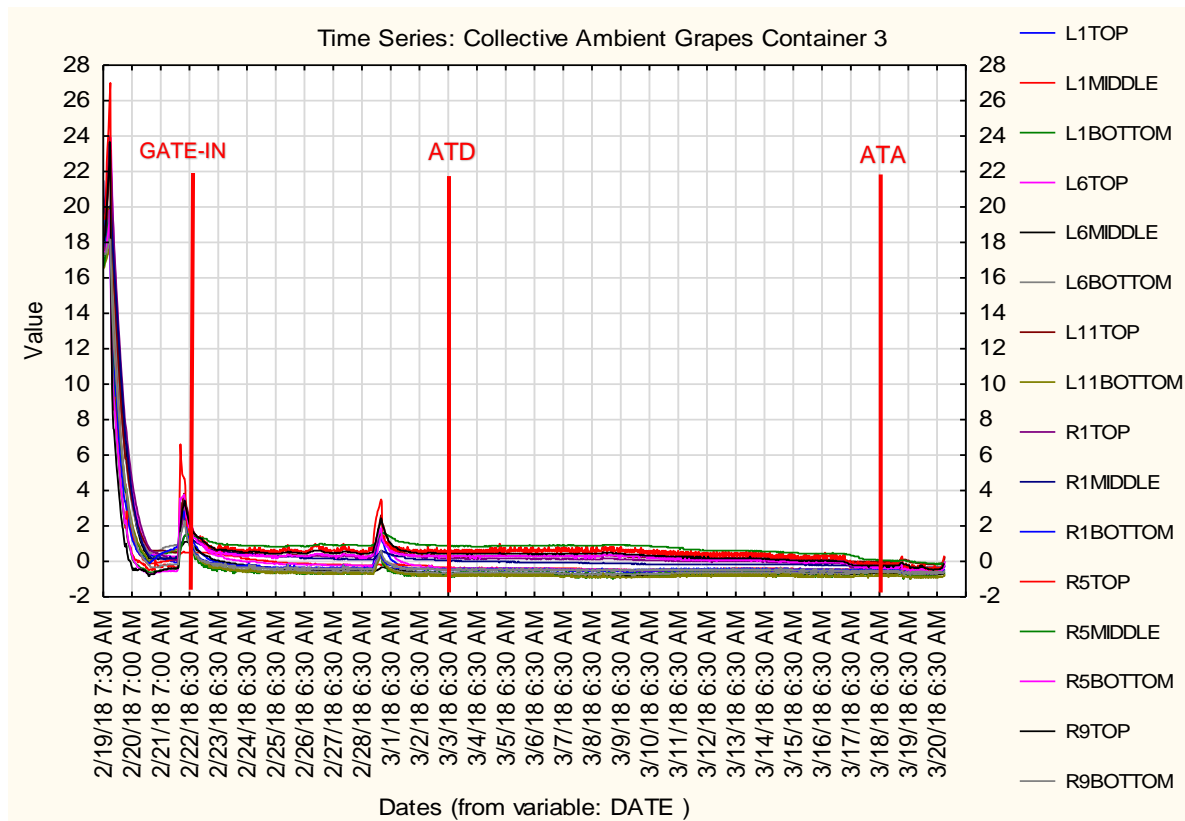


Figure 9.13 Time series line graphs of pulp & ambient temperature profiles of grapes container three

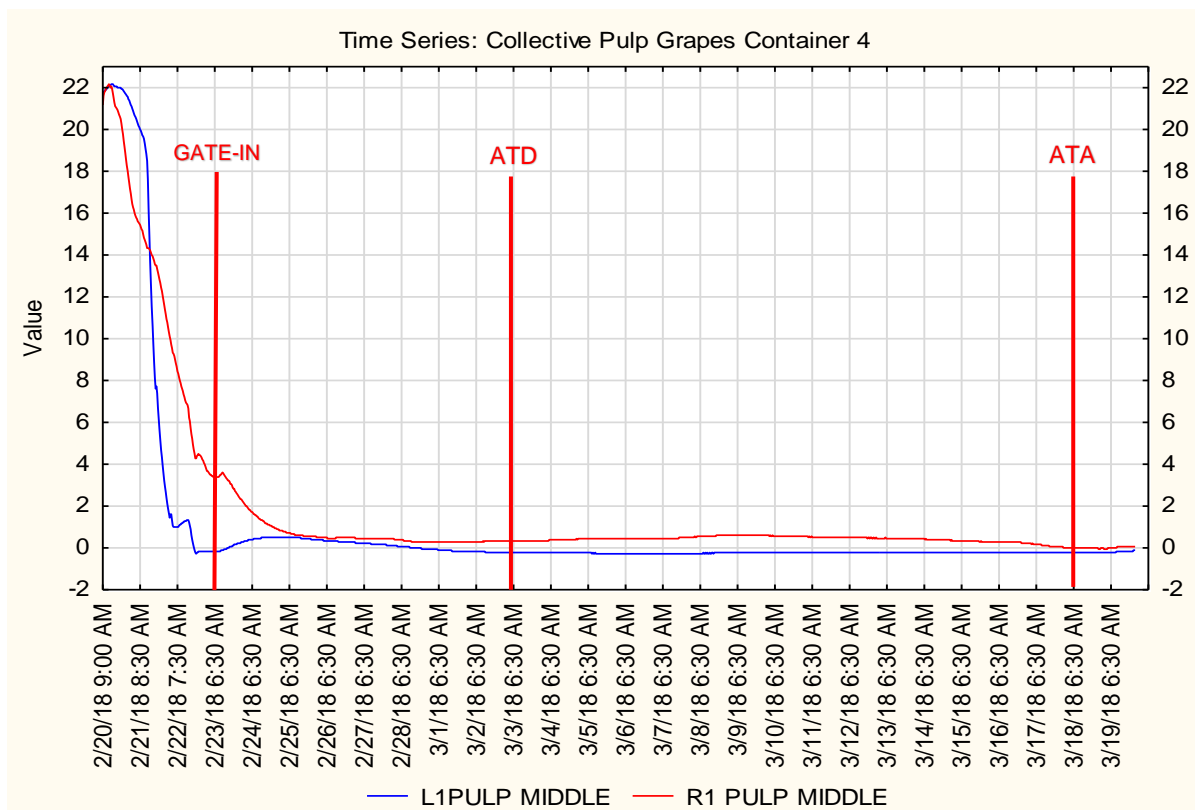
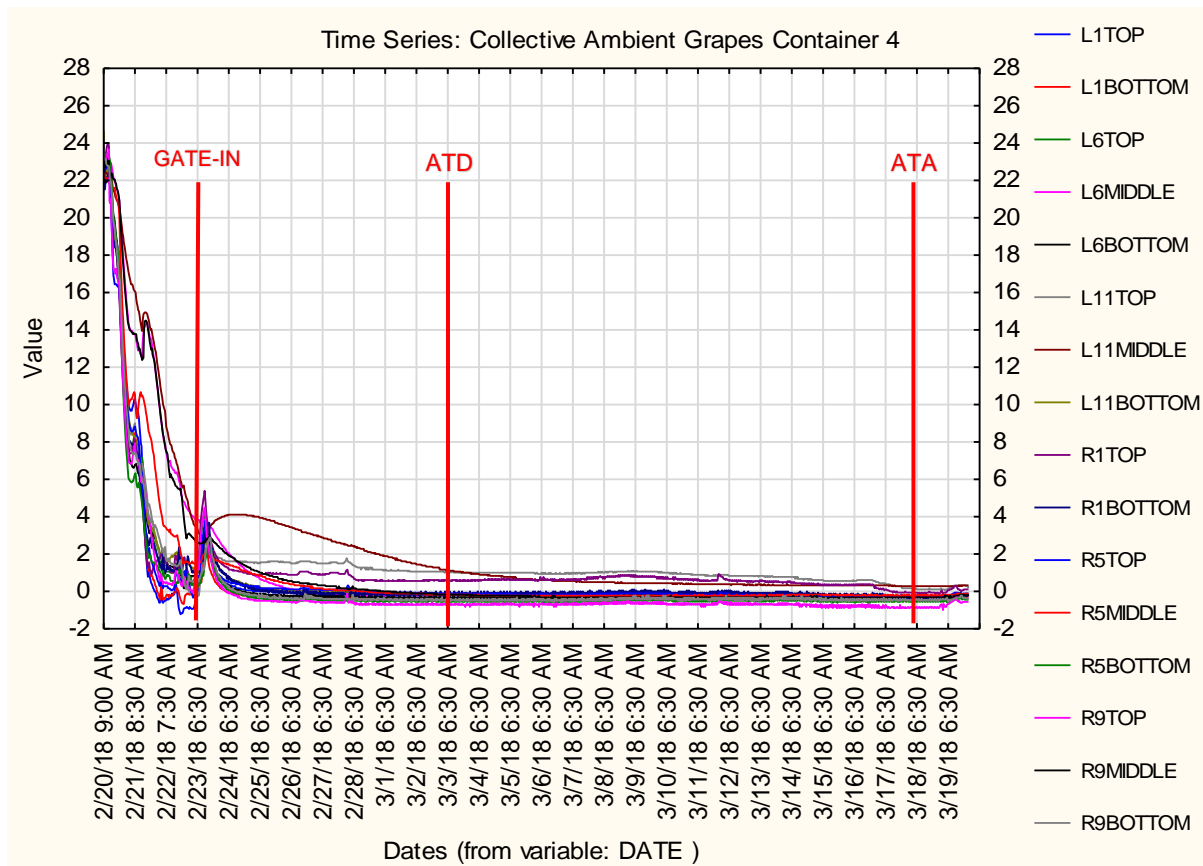


Figure 9.14 Time series line graphs of pulp & ambient temperature profiles of grapes container four

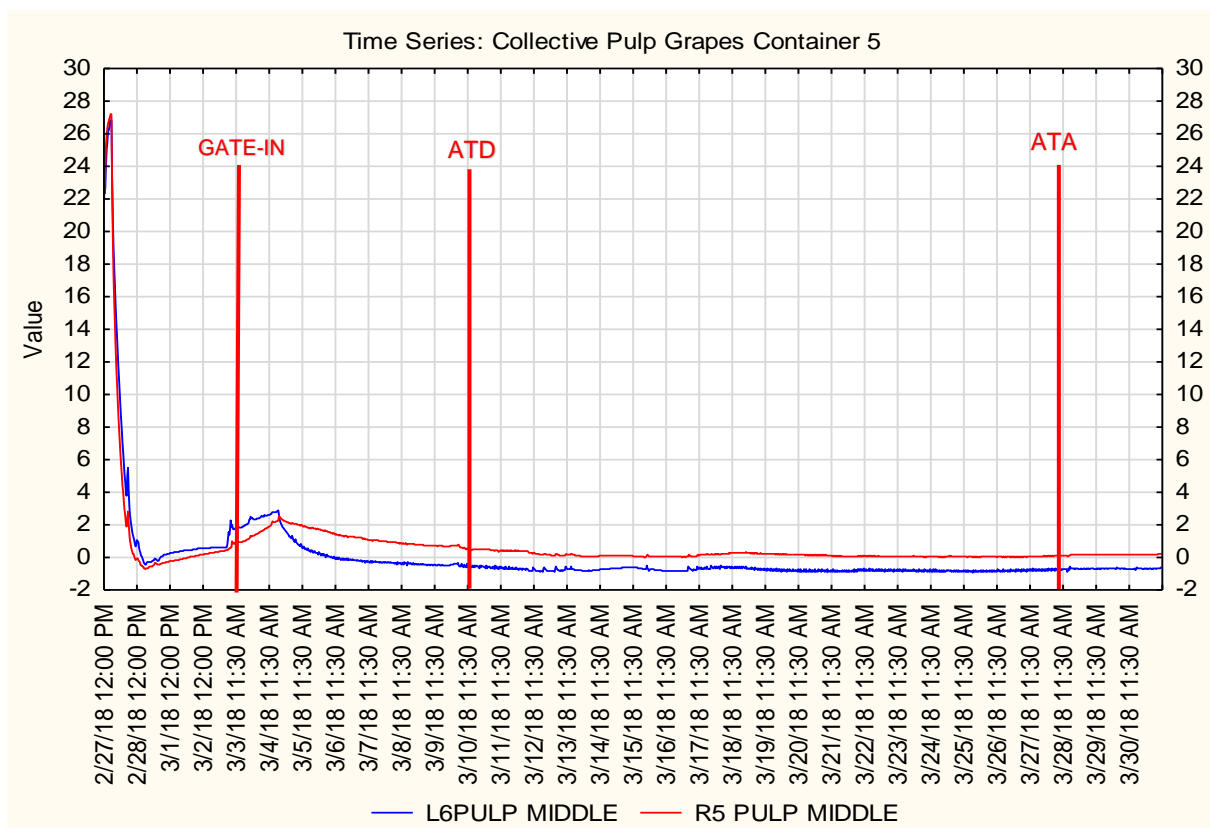
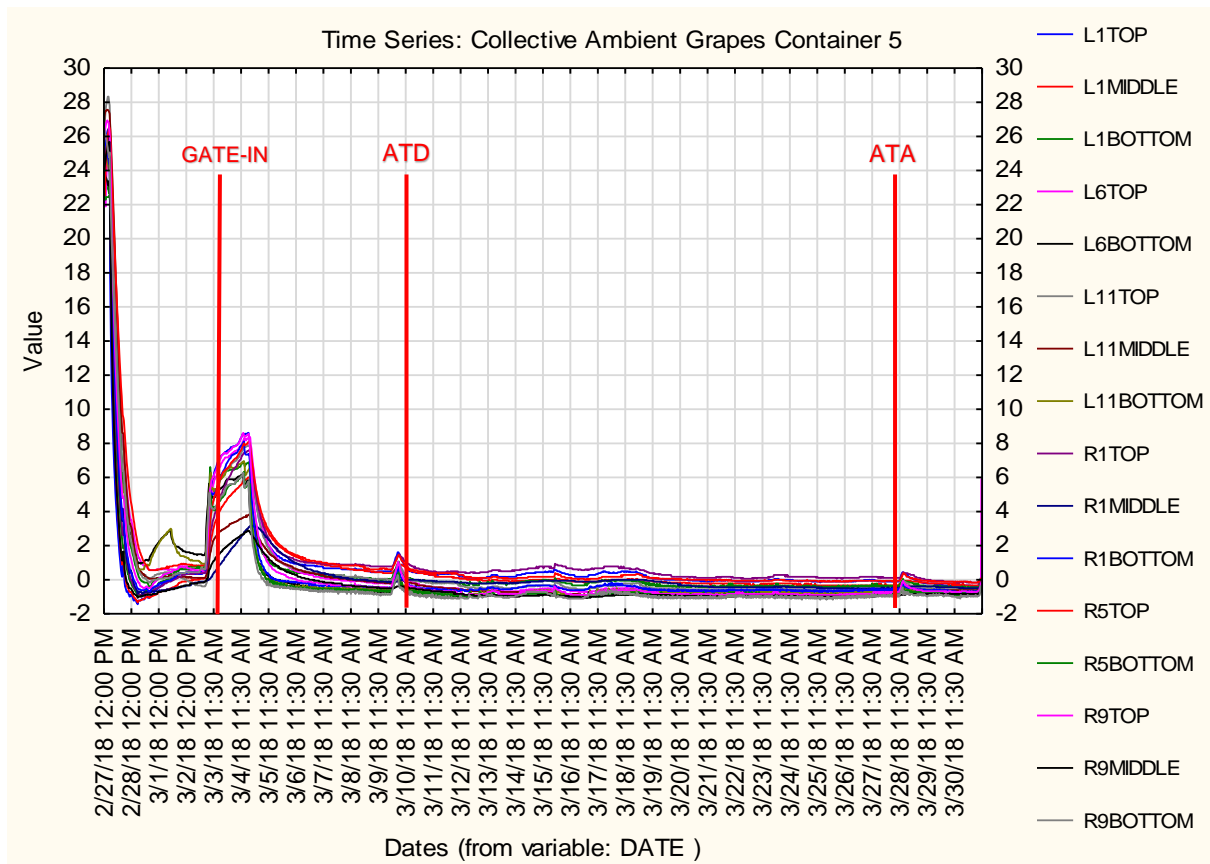


Figure 9.15 Time series line graphs of pulp & ambient temperature profiles of grapes container five

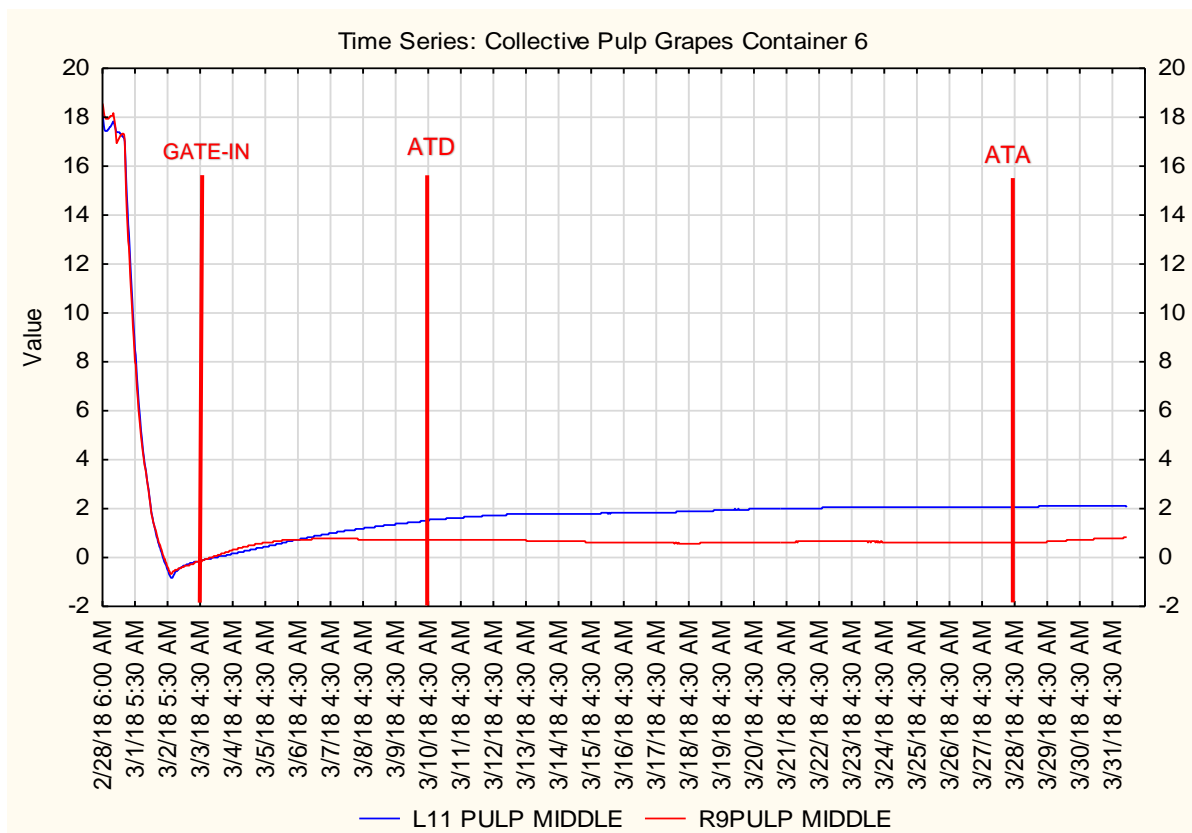
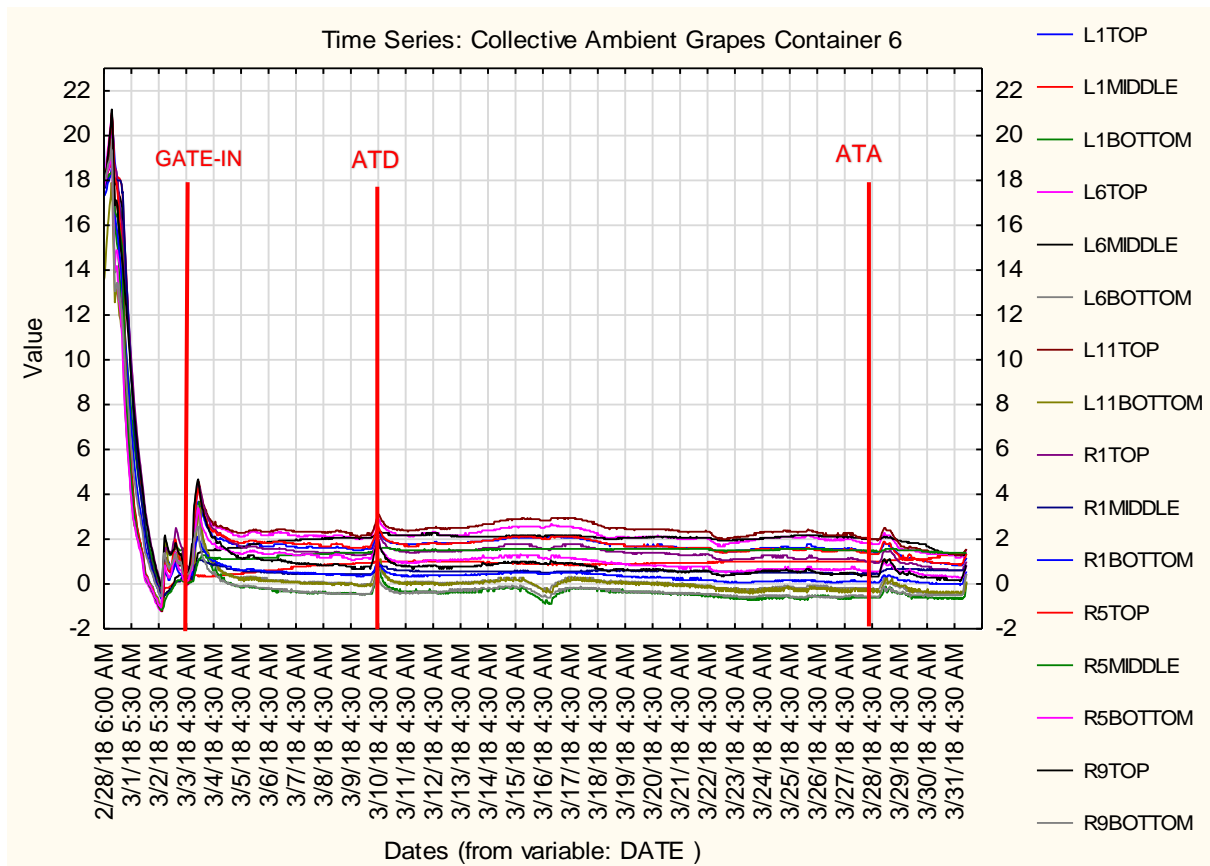


Figure 9.16 Time series line graphs of pulp & ambient temperature profiles of grapes container six

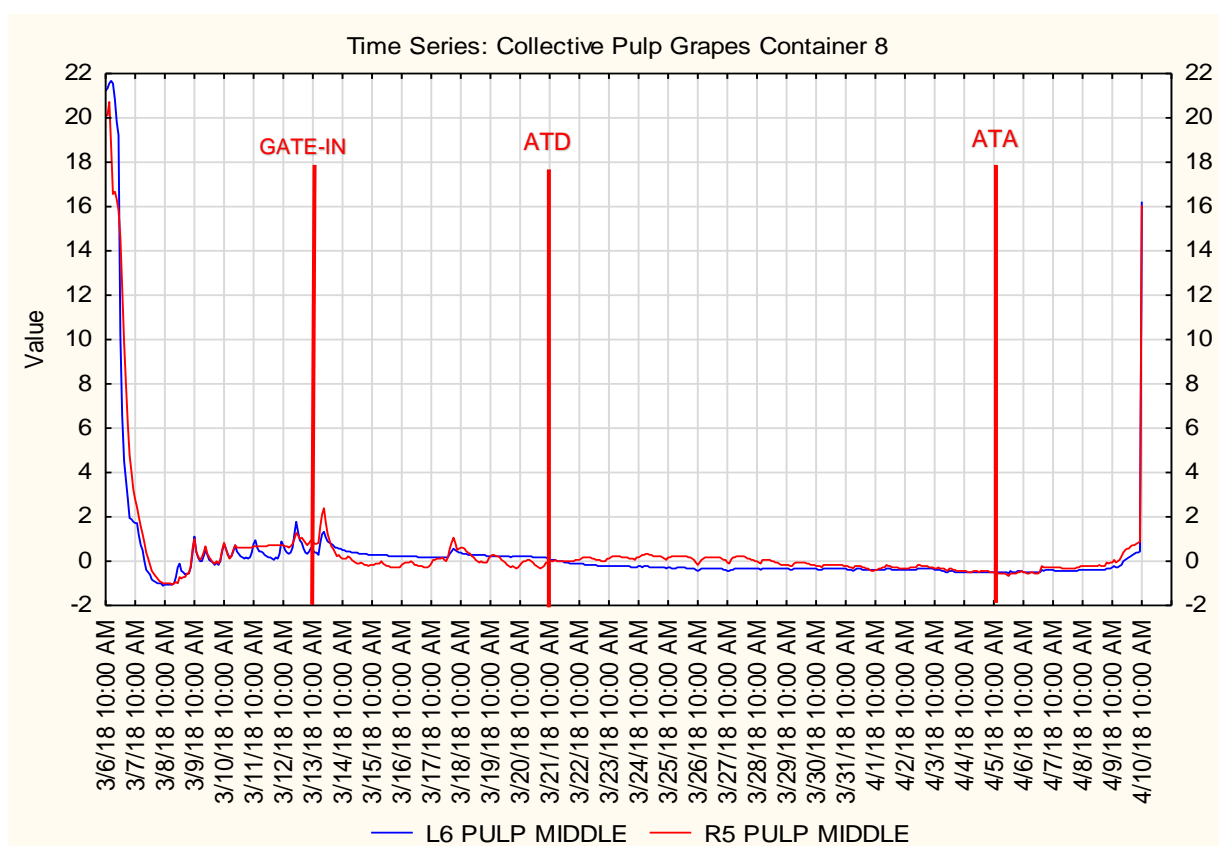
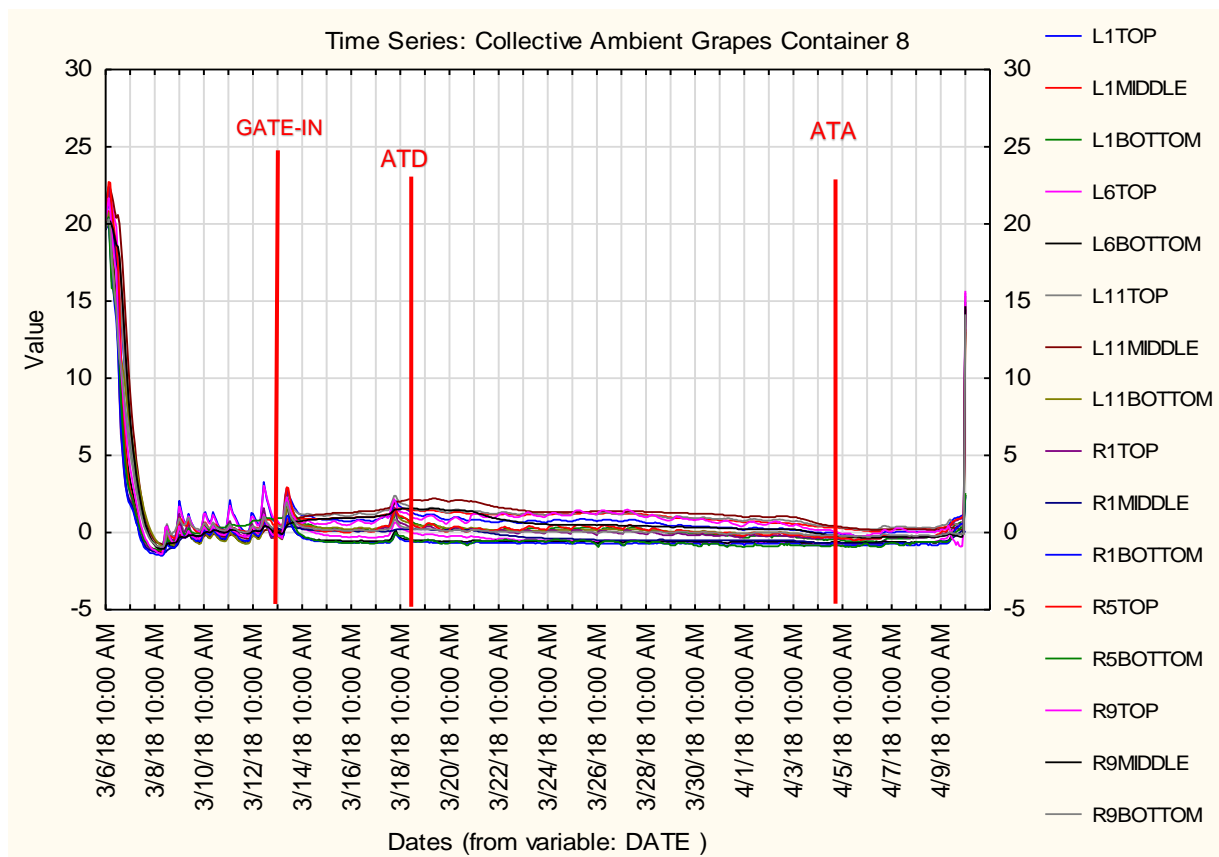


Figure 9.17 Time series line graphs of pulp & ambient temperature profiles of grapes container eight

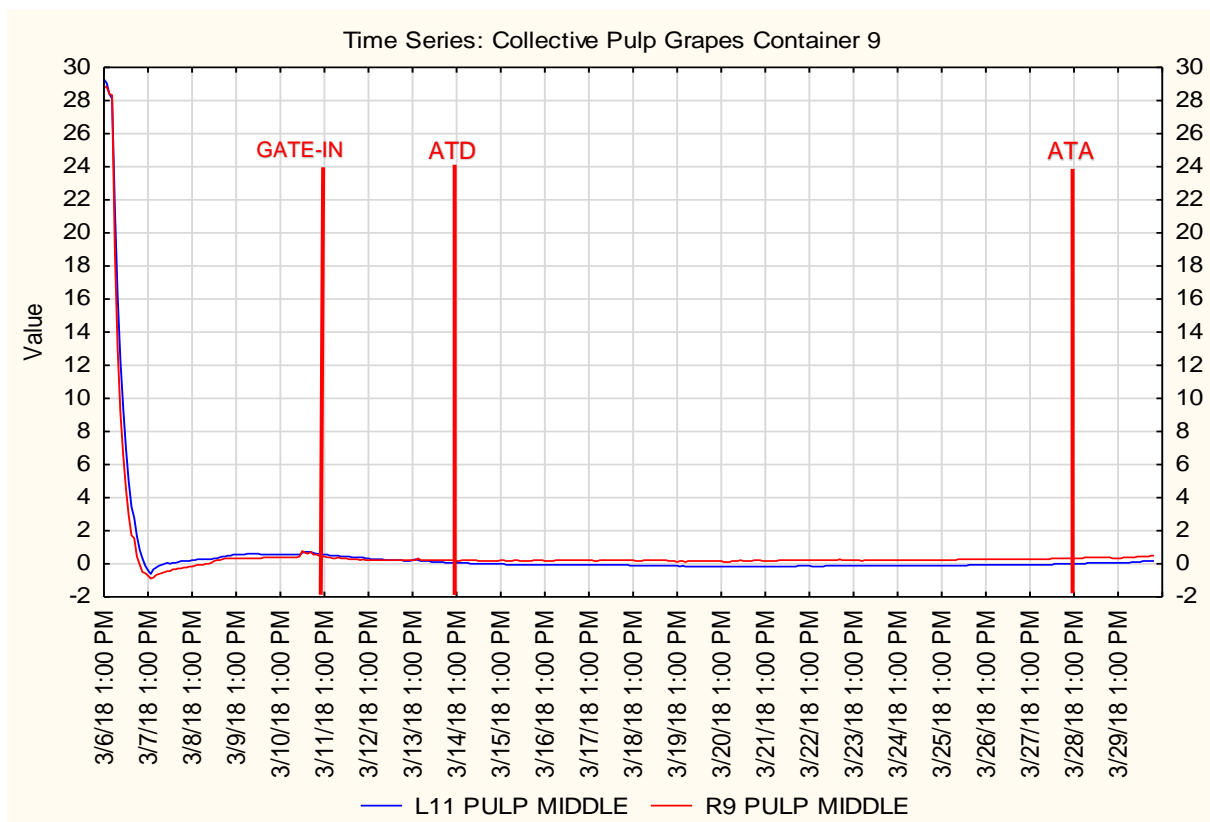
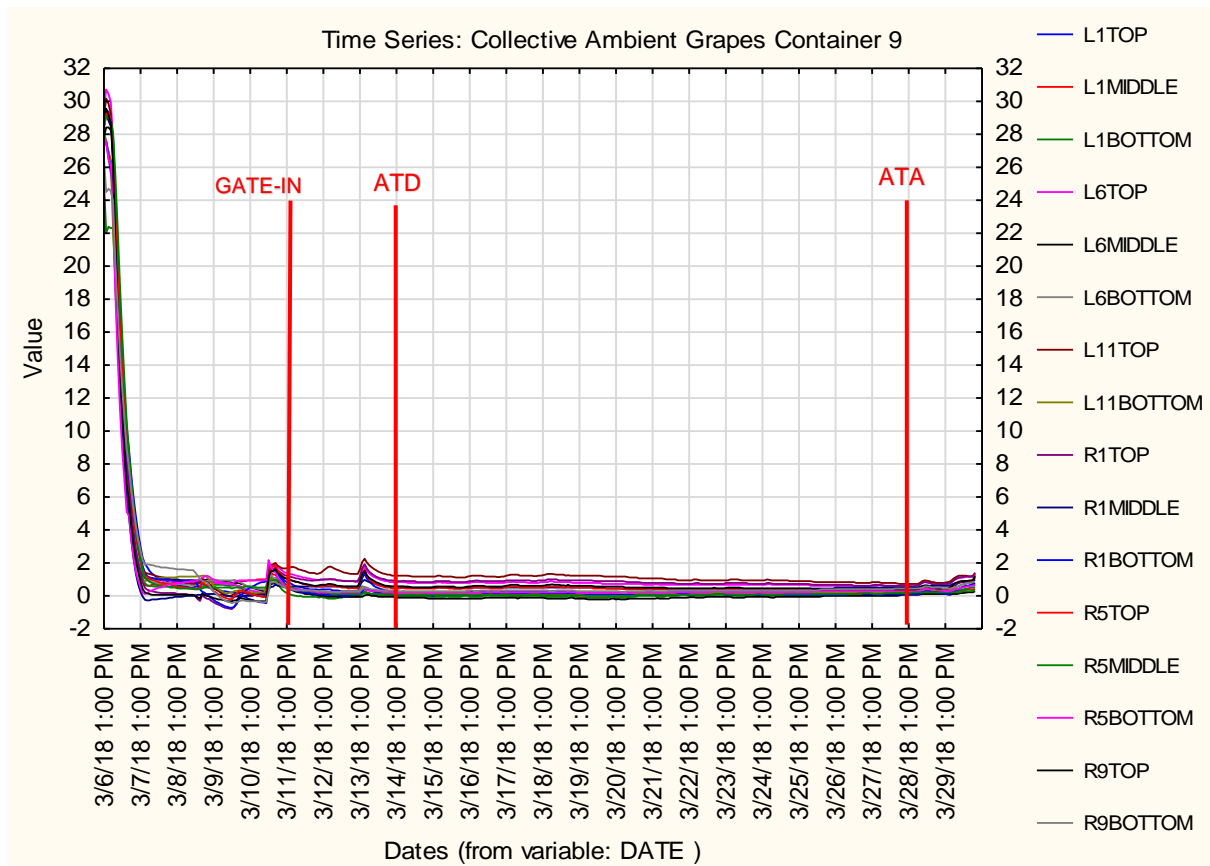


Figure 9.18 Time series line graphs of pulp & ambient temperature profiles of grapes container nine

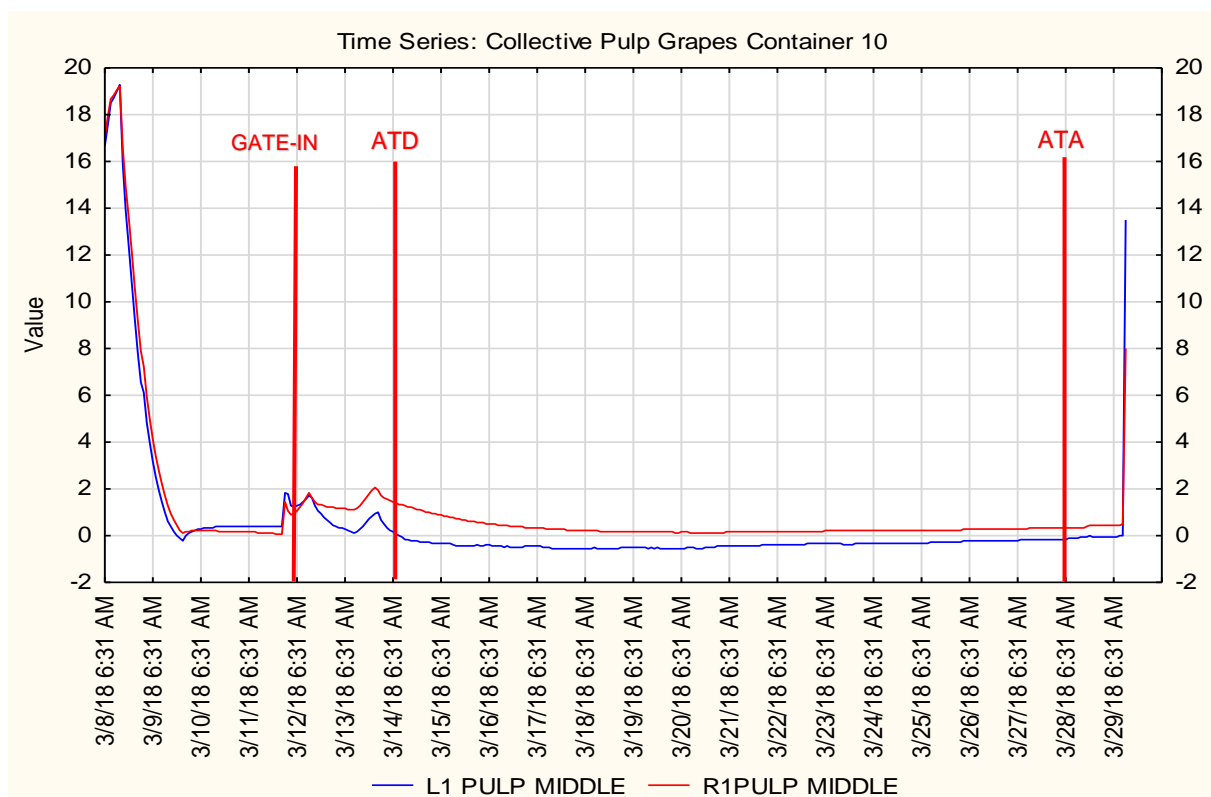
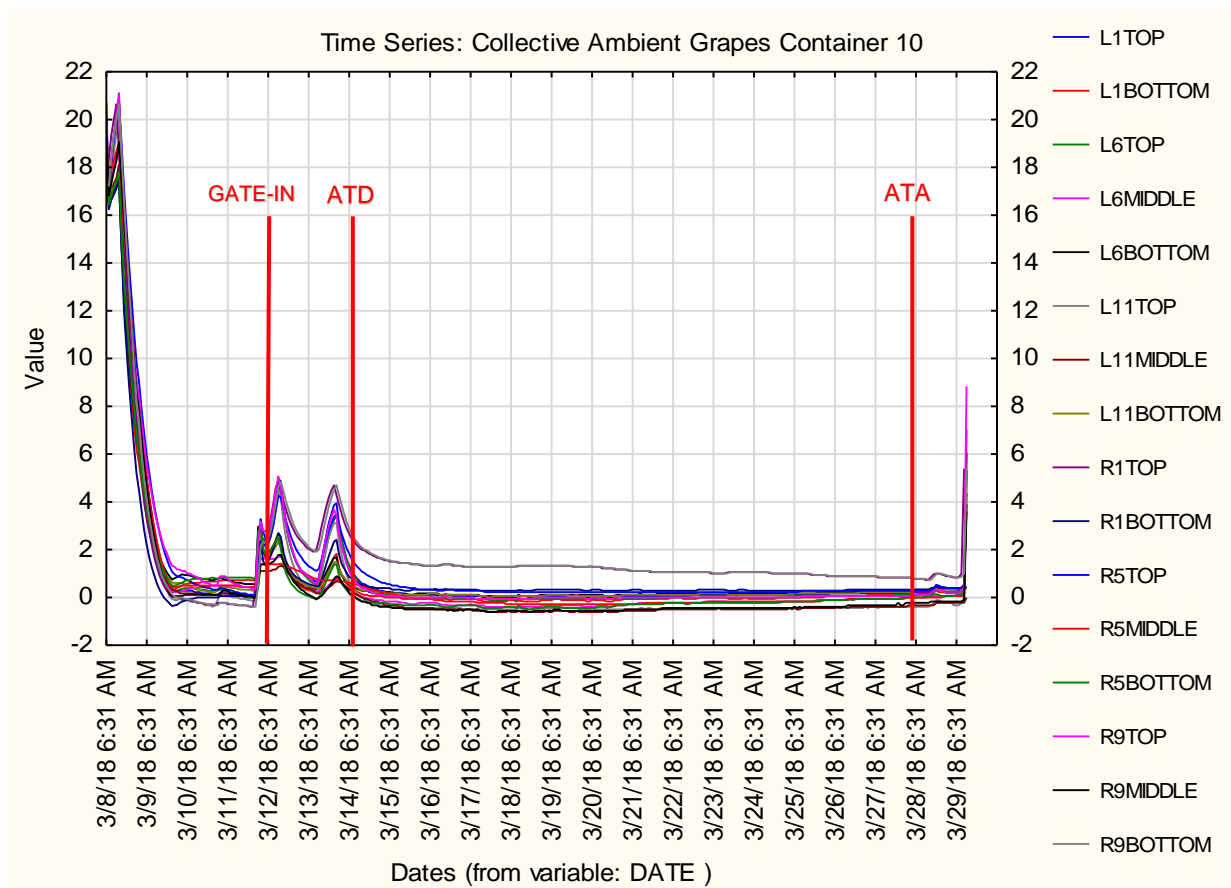


Figure 9.19 Time series line graphs of pulp & ambient temperature profiles of grapes container ten

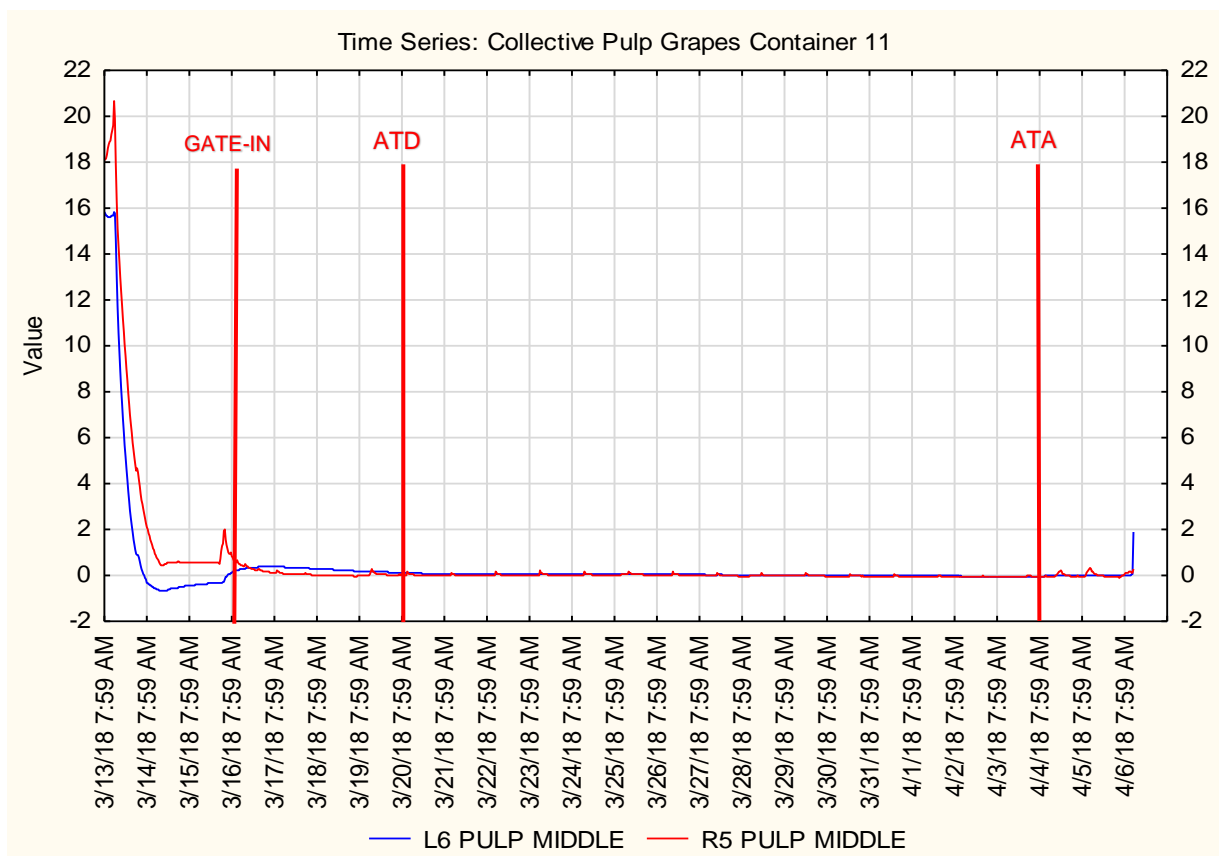
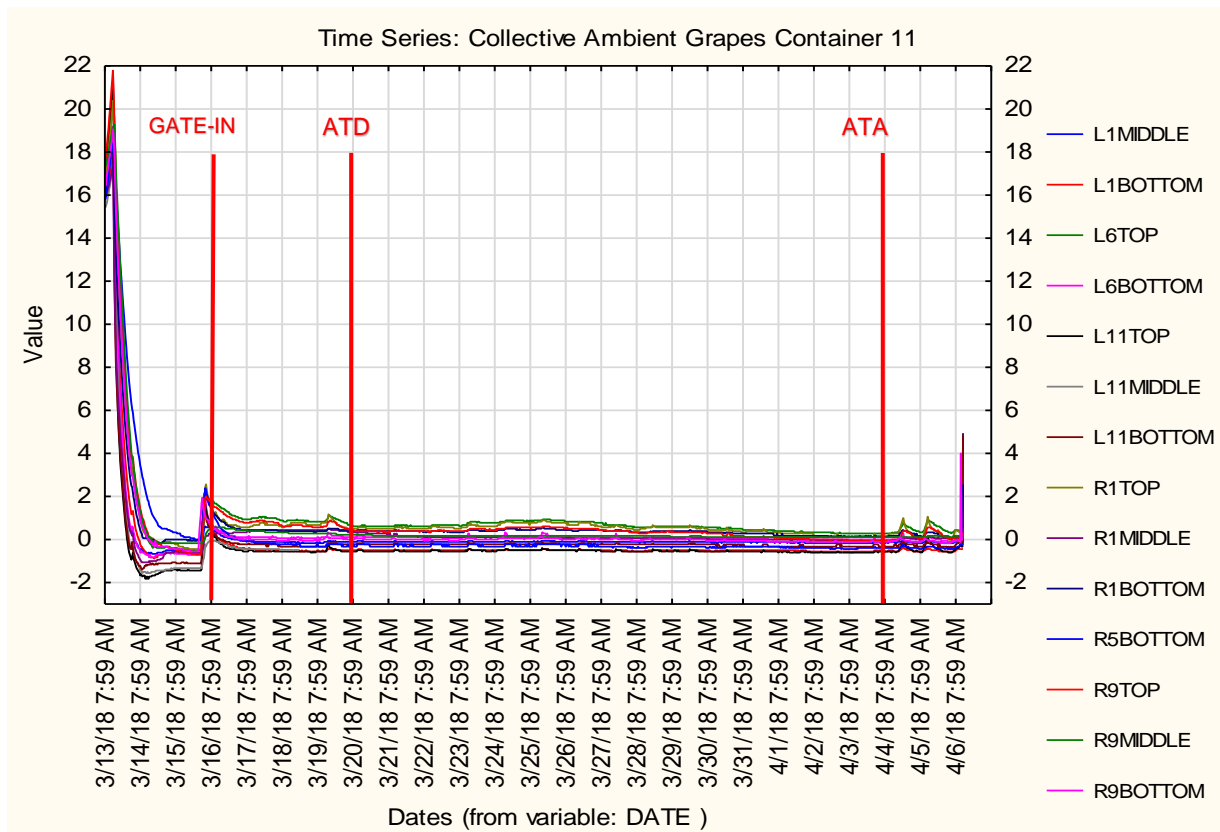


Figure 9.20 Time series line graphs of pulp & ambient temperature profiles of grapes container eleven

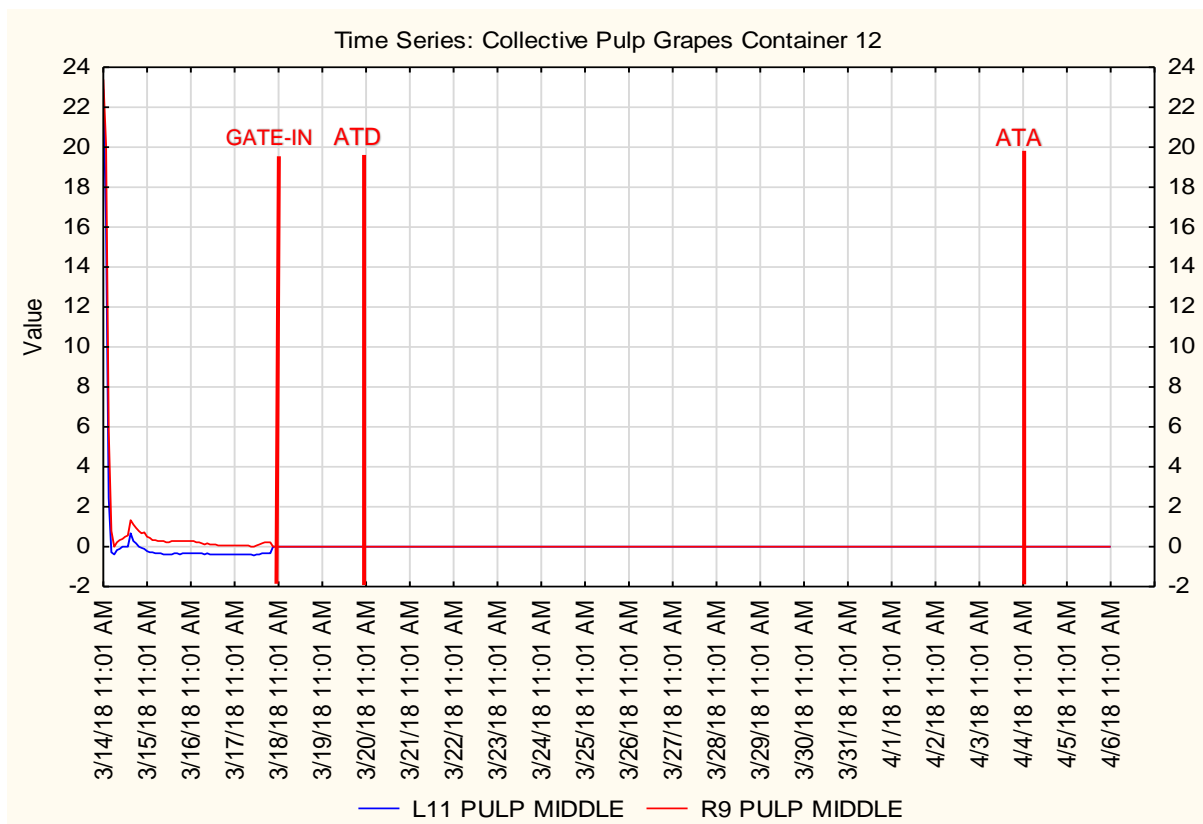
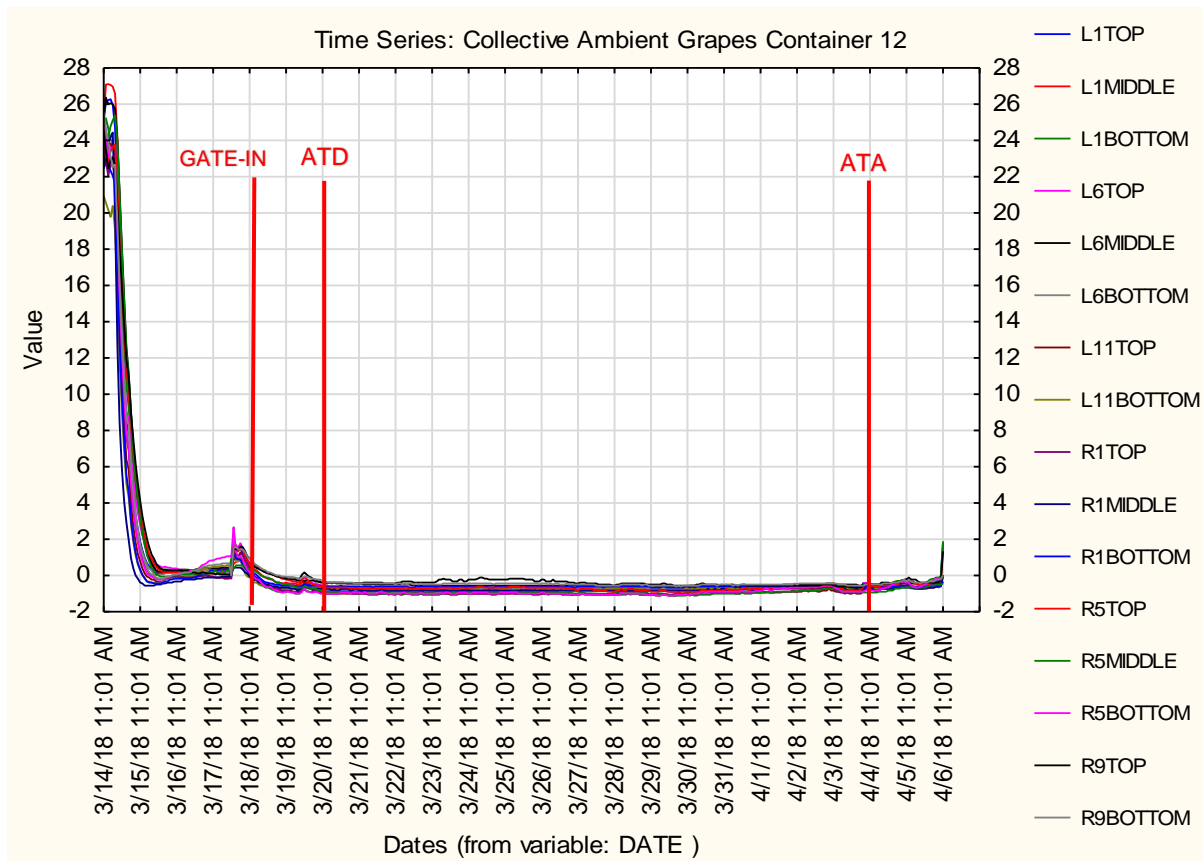


Figure 9.21 Time series line graphs of pulp & ambient temperature profiles of grapes container twelve